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# The Pathogenesis and Treatment of Eye Burns and Their Sequelae

MIR PUBLISHERS

*The Pathogenesis and Treatment of Eye Burns and Their Sequelae* describes the results of immunotherapy (the use of burn convalescent blood serum), and a therapeutic complex including non-surgical and surgical management of eye burns.

Much attention is devoted to keratoplasty in the early period of the burn process (urgent and early therapeutic corneal transplantation). The principal surgical interventions in severe cicatricial changes developing as a result of the burn and optic operations in leucomas (various types of keratoplasty, alloplasty in leucomas in which keratoplasty is not indicated, etc.) are described.

Ophthalmologists will find the book useful in their practice.

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Н.С. ШУЛЬГИНА
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# ПАТОГЕНЕЗ И ЛЕЧЕНИЕ ОЖОГОВ ГЛАЗ И ИХ ПОСЛЕДСТВИЙ

ИЗДАТЕЛЬСТВО «МЕДИЦИНА»
МОСКВА

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# The Pathogenesis and Treatment of Eye Burns

## and Their Sequelae

*Translated from the Russian*
*by*
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# Contents

*Introduction* . . . . . 7

*Chapter I.* PECULIARITIES OF THE PATHOGENESIS OF THE EYE BURN DISEASE (N.S. Shulgina) 11

The Main Aetiological Factors and Peculiarities of the Primary Damage to the Cornea in Burns of Various Aetiology . . . . . 12
Development of the Main Links of the Burn Process 24
The Role of Metabolic Disturbances in the Cornea in the Pathogenesis of Eye Burns 26
The Role of Auto-intoxication in the Development of the Burn Process in the Eyes 30
The Role of Autosensitization in the Development of the Burn Process in the Eyes 33

*Chapter II.* IMMUNOTHERAPY IN EYE BURNS (EXPERIMENTAL DATA) (N.S. Shulgina and V.M. Nepomyashchaya) 39

*Chapter III.* ASSESSMENT OF THE DEGREE OF SEVERITY OF BURN DAMAGE TO VARIOUS PARTS OF THE EYE (N. A. Puchkovskaya and V. M. Nepomyashchaya) 53

*Chapter IV.* CLINICAL PECULIARITIES IN THE DEVELOPMENT OF THE BURN PROCESS (N. A. Puchkovskaya and V.M. Nepomyashchaya) 62

Mild Eye Burns . . . . . 63
Moderate Burns . . . . . 65
Severe Burns . . . . . 69
Particularly Severe Burns . . . . . 77

*Chapter V.* THE PRINCIPAL METHODS OF DRUG TREATMENT OF EYE BURNS (N. A. Puchkovskaya and V. M. Nepomyashchaya) 84

First Aid (Removal or Neutralization of the Damaging Agent) . . . . . 85
Antibacterial Therapy (Prevention of the Development of Infection) . . . . . 86
Stimulation of Metabolic Processes and Regeneration in Damaged Ocular Tissues . . . . . 89

Anti-inflammatory Therapy (Suppression of the Inflammatory Process) . . . . . 94
Removal of Toxic Products Accumulating in the Tissue as a Result of Necrotic Disintegration 96
Immunotherapy (Influence on the Processes of Autosensitization and Auto-intoxication) . . . 97
Control of Remote Complications (Recurrent Inflammation) . . . . . 110

*Chapter VI.* SURGICAL TREATMENT OF EYE BURNS (N.A. Puchkovskaya) . . . . . 112

Urgent Keratoplasty . . . . . 115
Experimental Research . . . . . 116
Clinical Observations . . . . . 119
Early Tectonic Corneal Transplantation 120
Early Therapeutic Corneal Transplantation 123
Early Plastic Surgery of the Eyelids . . . 128

*Chapter VII.* SURGICAL TREATMENT OF CICATRICIAL CHANGES OF THE EYELIDS AND CONJUNCTIVA IN BURN SEQUELAE (N.A. Puchkovskaya) . . . . . 130

Correction of the Entropion of the Eyelids . . 130
Transplantation of Free Skin Grafts in Ectropion of the Eyelids . . . . . 131
Restoration of Free Margin of the Eyelid, the Canthus and Formation of Eyelashes . . . . . 136
Surgical Treatment of Extensive Symblepharons in Sequelae of Severe Eye Burns . . . . . 138
Elimination of Cicatricial Deficiency of the Conjunctival Cavity in Anophthalmos . . . 147
Prosthetics and Cosmetic Correction . . . . 149

*Chapter VIII.* OPTIC OPERATIONS IN LEUCOMAS OF BURN AETIOLOGY (N.A. Puchkovskaya) . . . . . 151

Extraction of the Cataract . . . . . 152
Keratoplasty . . . . . 157
Partial Lamellar Corneal Transplantation 159
Subtotal and Total Lamellar Corneal Transplantation . . . . . 160
Peripheral Lamellar Corneal Transplantation . . . . . 169
Corneal Alloplasty . . . . . 176

*Bibliography* . . . . . 186
*Author Index* . . . . . 202
*Subject Index* . . . . . 205

# Introduction

A main task of the Soviet health service is to prevent disease and accidents for which purpose wide development of safety measures in production, of health education and prophylactic medical service of all the population is foreseen. The automation of such branches of industry as chemistry, metallurgy, civil engineering and industrial construction plays an important role in preventing eye burns.

At present, however, the percentage of burns in proportion to the total number of eye injuries is still high, and ranges, according to published data, from 6.1 to 20.3 per cent, depending on the type of production and the economics of the field concerned.

Eye burns also occupy an important place among war injuries and are characterized by being both complex and combined in form. During World War II eye burns accounted for 6 per cent of all eye lesions.

Eye burns are rated among the severest lesions of the organ of vision both in the character of tissue changes and because, very often, both eyes are involved. According to some authors, 50 per cent of patients with severe eye burns become completely disabled and only few of them are capable of resuming their work.

Treatment of the consequences of burns is difficult, requires repeated complex plastic operations and is not always successful. Leucomas which develop after eye burns

greatly hinder keratoplasty, because they are vascularized and have the features of coarse scars. The growth of cicatricial tissue over the cornea, the development of extensive adhesions between the conjunctiva of the eye and eyelids complicate treatment even more.

The poor results of keratoplasty in leucomas forming after burns are often connected with a marked allergic reaction which naturally develops as a consequence of the heightened sensitivity of the organism following eye burns.

Comprehensive study of the pathological process in the eye caused by the effect of the damaging factor, and the organism's response reactions to the burn trauma appears to be very important owing to the possibility of finding pathogenetically directed methods for treating severe eye burns.

Biochemical investigations in various stages of a burn disease constitute an important stage in the research into the pathogenesis of eye burns. This trend made it possible for Soviet ophthalmologists to propose several vital measures which have fully justified themselves in treating eye burns (Kaznelson and Saushkina, 1950; Kaznelson, 1961; Puchkovskaya *et al.*, 1959; Pavlyuchenko, 1958, 1964; Zats and Dugelny, 1962; Chernova, 1964, 1965, 1967; Kaplunovich, 1964, 1966; Tartakovskaya, 1965, 1970; Ushakov, 1968, and others).

Extensive research into the pathogenesis revealed that in burn injuries of the eye the local process is paralleled by general changes in the body; changes in the white and red blood corpuscles, disturbances of certain functions of the liver and pancreas, changes in dehydrogenase activity of the tissues not affected by burns (the muscles, liver, brain) and so on. All these peculiarities, as well as the tendency toward recurrences of inflammation, and severe complications in comparatively later periods after the burn, gave rise to hypotheses regarding intoxication which deve-

lops in burns and causes disorders in the organism's general reactivity.

The results of experimental investigations carried out at the Filatov Institute of Eye Diseases and Tissue Therapy revealed the substantial role of auto-immune reactions in the development of the pathological process in burn injuries to the eyes and served as the pathogenetic basis for the immune therapy of eye burns.

A new method for treating eye burns with the burn convalescent serum has been developed in the Institute and the monograph describes the results of clinical observations during its application.

There has been much discrepancy of opinion up till now in assessing both surgical and non-surgical methods of treating eye burns. This is primarily connected with the lack of a single standard classification, as a result of which one and the same degree of severity of burns is interpreted in different ways by different authors.

We propose to supplement the existing classification of eye burns with characteristics of early attending symptoms encountered in the very first days after the burn injury, which help define the severity and extent of the damage more fully.

A detailed clinical description of damages caused by burns (depending on the degree of severity) and complications arising during the burn process is given on the basis of the analysis of 642 case histories of patients with eye burns (943 eyes).

The principles of comprehensive pathogenetic therapy, indications for operation and the techniques of various surgical interventions, both in the early stages of the burn process and in its severe consequences, have been worked out on the basis of many years' experience of the Burn Department of the Institute and generalization of data on the morphological, biological and immunological disorders caused by eye burns.

The application of newly proposed operations on the eye, which have been tested at the Institute, made it possible to restore vision in cases with severe sequelae of eye burns, sometimes even in 'hopeless' ones.

The photographs were produced by the laboratory of scientific photography of the Filatov Institute (head of the laboratory E.G. Shaier); the illustrations of operative techniques were made by artist B.A. Bamsky.

The authors hope that this monograph will help ophthalmologists in their practical work and that the tasks set will promote study of the burn disease of the eyes on a wider scale.

CHAPTER I

# Peculiarities of the Pathogenesis of the Eye Burn Disease

The interest of ophthalmologists has long been focussed on eye burns. For a considerable time the problem was developed by studying the clinical picture of the burn process. In time, the literature dealing with eye burns was supplemented by investigations of a histomorphological trend and new recommendations for treatment appeared. Later, between the end of the thirties and the beginning of the fifties, new works were published which substantially cleared up the question of chemical reactions taking place immediately the damaging substance comes into contact with the biochemical components of the cornea, throwing light on those reactions which serve as the trigger mechanism in the complex process involving the eye after a burn. These investigations laid the foundation for the classification of damaging substances and factors.

It was only at the end of the fifties that publications began to appear, mainly in Soviet literature, which gave the first data on research into the pathogenesis of eye burns. The desire to comprehend the essence of the burn process in the cornea was based primarily on the necessity of finding sufficiently effective measures for treating severe burns. During the past decade a few circumstantial works were published in this field, which, for the most part, studied metabolic disturbances in various corneal tissues after a burn and their significance for the vital activity of the cornea.

We also examined another aspect of the pathogenesis—the cause and the role of disturbances in the whole organism's reactivity to burns.

In addition to a brief description of the basic aetiological factors causing burns, this chapter is devoted to two questions, which, as we see it, are very important for un-

derstanding the pathogenesis of the burn process. One question involves the peculiarities of the direct effect of various damaging agents on the corneal tissue and the reasons for the uniform character of the pathological process, irrespective of the aetiology. The other question concerns the main biochemical and physiological changes developing in the tissues of the burnt cornea and the cause of autoimmune processes. Our many years' investigations underlie the data on the origin of autosensitization and the role it plays in the development of the burn disease of the eyes.

## THE MAIN AETIOLOGICAL FACTORS AND PECULIARITIES OF THE PRIMARY DAMAGE TO THE CORNEA IN BURNS OF VARIOUS AETIOLOGY

In ophthalmological literature two main groups of burns are distinguished according to aetiology.

Group I comprises burns caused by physical factors, among which the most common is the thermic factor.

Group II embraces burns due to contact with chemicals, which are more common in peacetime. According to Kaznelson and Saushkina (1950), and Isaeva (1960), the incidence of chemical burns is more than double that of thermal ones; according to Rodigina *et al.* (1964) it is 4.5 times, while, according to the Filatov Institute, it is 3.2 times greater.

Chemical burns are a great hazard for the eyes not only because they occur more frequently, but also because the lesions resulting from them are often much more severe, though, of course, both a thermal and a chemical factor may produce a severe, a particularly severe, or a mild burn, since the severity of the lesion is determined by many factors, particularly the temperature, concentration and the amount of the acting agent, the area of the affection and certain other factors.

There is a large variety of chemical substances which can cause eye burns, and it would be difficult simply to enumerate them. The sensitivity of the corneal tissues to the damaging effect of many substances is determined by the absence of a layer of keratosic epithelial cells which could provide mechanical protection for the tissues by continuously moistening the cornea with tears and providing close contact between the cornea and the chemical on

its surface. The absence of vessels is also of much importance, since cell-decay products are accumulated more easily, while conditions for physiological discharge of the chemical penetrating the corneal tissues and for rendering it harmless become more difficult. It is also very important that metabolism in the cornea is mainly effected through the epithelium and endothelium. The damage of the epithelial cells when brought in contact with most of the chemical substances leads to disturbances in metabolic processes.

A vast number of substances which cause damage to the tissues of the eye (the cornea, conjunctiva) with reference to the production processes using them was listed by Zagora (1961). He names no less than 150 various substances and their derivatives.

Grant (1950) classified the aetiological factors of chemical eye burns according to four types of their injurious effect: (1) change in the concentration of hydrogen ions in the internal and external environment of cells; (2) denaturation of proteins by the addition of simple chemical substances; (3) change in the products of intermediate metabolism from interaction with them; (4) suppression of oxidizing processes in the tissues.

Duke-Elder (1954) gives a more detailed classification of harmful substances based on their chemical properties.

In practice only two aetiological groups of chemical eye burns are often taken into consideration: burns caused by **acids** and burns caused by **alkalis.**

Two stages may be conditionally distinguished in the clinical picture of burn injury: (1) primary (direct) damage to the eye tissues; (2) the development of the basic links of the burn process.

The aetiology of the primary chemical or thermal injury far from always predetermines the course of the burn process. It determines the character of the primary damage and the large variety of pathological and biochemical mechanisms that begin operating. This provides grounds to regard the mechanism of the primary (direct) damage inflicted by this or that burning agent in association with the aetiology of burns, having conditionally separated the primary damage from the successive chain of pathological changes comprising the picture of a typical burn process, which we call the eye-burn disease (Puchkovskaya *et al.*, 1959).

**Thermal burn.** Thermal burns are caused by the injurious effect of high temperature. According to the data of the in-patient department of the Filatov Institute of Eye Diseases and Tissue Therapy for 1961-1971, the most frequent cause of thermal burns were traumas inflicted during work by smelted metals, red-hot slag, flames, hot water and steam.

Burns caused by steam and hot water occupy a special place. Due to the chemical indifference of water they may be regarded as purely thermal injuries not complicated by the effect of an active chemical substance. Water heated to a temperature of 45°C is injurious to the cornea; at 47°C it makes the corneal epithelium cloudy in one or two minutes, at 65°C the stroma suffers and oedema of the corneal lamella is observed; at 80°C obvious changes occur in the endothelium. The tissues of the iris and the crystalline lens are also damaged.

Thermal burns in production are most often caused by hot metals. The temperature of a drop of molten metal or metal shaving is usually not known, but it is usually very high corresponding to the following melting points: 280°C for tin, 330°C for lead, 419°C for zinc, 960°C for silver, 1083°C for copper, 1530°C for iron, etc. Due to the high heat conductivity of metal, however, the time of action lasts for a split second, particularly if only a tiny drop gets in the eye. At the moment it contacts the eye a gaseous layer forms between it and the eye surface owing to the evaporation of tears from the surface of the cornea and conjunctiva, which protects the eye tissues and may somewhat alleviate the pain of the victim.

Many researchers (Campbell *et al.*, 1950; Puchkovskaya *et al.*, 1959) studied the reaction of the cornea to a thermal burn in experiments, producing the burn by thermocautery or by contact with hot metal. Campbell *et al.* (1950) note that the localization of the burn may determine the severity of the lesion. A burn occurring at a distance of 3 or 4 mm from the limbus takes a milder course.

Morphological disturbances in the cornea, which arise immediately after an experimental burn, have been described by various authors. Lebekhov (1958) noted that in a thermal burn the epithelium and Bowman's membrane are the first to be damaged. The epithelium is torn off, Bowman's membrane is partially destroyed and the stroma is

considerably damaged through all its thickness. Despite its insignificant thickness (0.006 mm), Descemet's membrane often proves to be relatively resistant after a burn. In rare cases, and more often in later periods, it fails to withstand the intra-ocular pressure, stretching and rupturing.

It has been established by phase-contrast microscopy that in corneal burns coagulation of colloids takes place, first of all of the cell nucleus and, as the lesion progresses, it is also observed in the cytoplasm.

The changes in the colloid caused by the effect of high temperature ultimately lead to the arrest of movement in the protoplasm. They may be reversed if the damaging effect is eliminated in time (Nasonov and Alexandrov, 1940). By means of ultramicroscopy Heinc *et al.* (1967) succeeded in establishing that disturbances develop within the cells at submolecular level. These investigations confirm on the whole the observations made earlier and, at the same time, supplement them considerably, demonstrating the dynamics of disturbances in the cell organoids.

Muchnik studied the functional disturbances developing in a cell under the influence of a thermal burn of the cornea (Puchkovskaya *et al.*, 1959) by the method of intravital staining (Nasonov and Alexandrov, 1940).

The method is based on the property of a living cell to counteract penetration of its body by a foreign substance including a vital dye; with the growing affection of the cell its resistance wanes and the dye penetrating it spreads diffusely in the cytoplasm. The authors of the method called this condition of the cell **paranecrosis**, emphasizing the reversibility of the injury after the acting factor was eliminated. The functional condition of the cells of the epithelium, stroma and endothelium may be judged by observing their reaction to the staining solution in various periods after the burn.

In these experiments with corneal burns caused by molten metal with a melting point of 250 °C it proved possible to show that from the very first hour after the burn the zone of damaged cells expanded, spreading radially from the site of the burn in all layers of the cornea.

The damaging effect of the thermal factor is manifest not only with a rise in temperature, but also with its fall, which leads to protein denaturation and cell destruction.

In cases of deep freeze the outcome of the process is characterized by the development of vascular leucomas, staphylomas and other similar complications. To emphasize the similarity of the lesions in the eye produced by thermal burns or congelation, Duke-Elder (1954) notes that treatment in both instances is the same.

In recent years due to the wide application of cryotechniques in ophthalmology, much interest has been aroused in corneal frostbite. Cryo-extraction of the crystalline lens and cryotherapy in diseases of the cornea require study of the corneal reactions to frostbite, which may occur as a complication during the performance of these manipulations. According to Kolstad and Opsahl (1969), a temperature of —79°C to —190°C is tolerated on a limited area of the cornea without any consequences during an exposure lasting no longer than one minute.

Histomorphological disturbances in the corneal tissue are preceded by biochemical shifts caused by the direct effect of the damaging factor. Before all else, this is the thermal denaturation of protein followed by a chain reaction organically connected with it.

To avoid repetition of information on the biochemistry of the tissues of a healthy cornea we shall merely refer the reader to the book by Pirie and Wan-Heining (1968) which provides the necessary data on the problem, and point out that the principal active substances are contained in the corneal epithelium. In a burn caused by any factor with involvement of the epithelium metabolic processes in all the tissues of the cornea are sharply disturbed: a deficiency of ascorbic acid, riboflavin, glutathione, nucleic acids and lipoproteins develops, the enzymes disintegrate and glycogen is destroyed. With the disintegration of enzymes the functions of respiration, oxidation and reduction are suppressed (Kaznelson, 1955). Histochemical study (Christensen *et al.*, 1955) established that the condition of collagen changes under the effect of the thermic factor. The endothelium like the epithelium is a very active structure providing for metabolism.

Denaturation of a protein molecule in a thermal injury varies in character (Flosdorff and Chambers, 1935). Destruction of proteins may lead to the formation of toxic products. Many authors (Passow, 1939; Filatov, 1945; Khayutin, 1961; and others) mention that a similar condition

develops in corneal tissues in a thermal burn. But in recent years this assumption has not been experimentally confirmed.

It thus proceeds from the above stated that primary (direct) damage inflicted by a thermal factor is characterized by the destruction of the epithelial cells on a more or less extensive area of the cornea and the development of paranecrosis of cells which lie in close proximity to the site of affection. The condition of paranecrosis spreads extensively and deepens after the action of the thermic agent has ceased.

The following factors may cause the advancement of tissue damage: (1) disturbances of metabolic processes due to loss of epithelial cells; (2) disturbances of water balance owing to damage of the borderline layer of epithelium and endothelium; (3) the formation of toxic products from molecular fragments of damaged cells; (4) the development of new antigenic characteristics of protein molecules following exposure to thermal denaturation, which may lead to autosensitization.

Bearing in mind the peculiar anatomical and physiological position of the cornea and the absence in it of blood vessels supplying tissues with substances essential for their vital activity, and removing the disintegration products from them we may assume that the accumulation of toxic products after a corneal burn will be rather more intensive than after a burn of the skin, and their secondary damaging effect may be marked despite the small area of affection.

**Acid burn.** The severity of a burn caused by acids depends on their concentration and length of action, and also on their anions (Grant, 1952). The anions of certain acids have marked affinity to proteins, owing to which the damaging effect occurs at not very low pH values. The damaging effect of hydrochloric acid, for instance, is manifest at pH 2.5, whereas trichloroacetic acid, possessing an anion with a higher affinity to protein, injures tissues at pH 4.5.

Among the inorganic acids, sulphuric, hydrochloric and nitric acids cause damage most frequently. Just as in extracts, proteins coagulate in living tissue when there is a shift in the concentration of hydrogen ions to the acid direction, forming an insoluble acid proteinate. The process may be reversible (with a low acid concentration and li-

mited time of exposure), while, with sufficiently intensive action, it may lead to severe lesions of the tissue. Certain derivatives of these acids have a similar effect: very severe burns are caused by vapours of chlorosulphonic acid of a high concentration (a substance used for smoke-screens). Organic acids usually penetrate the corneal tissue poorly, leaving white necrotic masses on its surface; after they are discarded, the defect heals rapidly from the periphery (carbolic acid).

Acetic acid ($CH_3COOH$) acts in a different manner, damaging not only the surface, but also the deep layers of the cornea. Glycollic acid ($C_2H_4O_3$) and thioglycollic acid ($C_2H_4O_2$) used as a hair-dye cause sharp irritation on contacting the eye with the resultant stable opacity of the cornea (Carpenter and Smith, 1946; Harley, 1953).

Anhydrides of organic and inorganic acids cause deeper injuries to the eye tissues than the acids themselves. This is explained by their double action: when on the cell surface they dissolve lipids (constituents of the cell bordering membrane) and penetrate deep into the tissues; in an aqueous medium they turn into acids, in other words, in their ability to penetrate deep into the tissues they resemble alkalis, while in the character of their effect on a protein molecule they resemble acids (Carpenter and Smith, 1946; Harley, 1953).

Pathomorphological changes in the corneal tissue produced by the direct effect of an acid have been the subject of investigation by many authors time and again (Berezinskaya, 1936, 1940; Friedenwald *et al.*, 1946; Puchkovskaya *et al.*, 1959; Tartakovskaya, 1968). Various authors encountered a generally similar histological picture immediately after burns by sulphuric, hydrochloric and nitric acids of a sufficiently high concentration (from 10 to 30 per cent). In the first hour after the burn the epithelium on the corneal surface is preserved but seems to be fixed. An acid of a higher concentration may partly destroy it. In the stroma the damage to the corneal cells is strictly confined to the burn area; damage to the endothelial cells is likewise limited. After several hours have elapsed the process spreads along the surface and in depth. New cells which had escaped damage at first now become involved, necrobiosis of the nuclei of the corneal corpuscles develops attended by infiltration of the cornea with formed elements

of white blood. The disappearance of corneal cells from the stroma and the loss of the structure of Bowman's capsule stipulate the transformation of the tissue into a homogeneous mass. With an acid of a high concentration these disturbances become organized in 8 to 24 hours after the burn and lead to irreversible changes.

In the opinion of a number of authors (Berezinskaya, 1940; Friedenwald *et al.*, 1946; and others) acid burns of the cornea result in the damage of a non-progressive character. This judgement is grounded on the information that the action of an acid brings about chemical transformation of proteins into insoluble acid albuminates, forming a sort of a barrier which prevents penetration of an acid deep into the tissue. Actually, however, under the influence of secondary factors the zone of affection always expands as compared to the zone of direct contact between the cornea and an acid. Damage to the epithelial cells resulting from an acid burn like in a thermal burn leads to profound deficiency of active biochemical components in the epithelial layer. The loss of glycogen and vitamins and disturbances in the respiratory function inevitably result in deep changes of physiological and biochemical processes (Chernova, 1969; Tartakovskaya, 1970).

Muchnik's histomorphological studies (Puchkovskaya et al., 1959) testify to progressive damage of the corneal tissue in burns by a 20 per cent solution of sulphuric acid. Soon after the burn the affected area grows, spreading to deeper lying layers of the tissue down to the endothelium. Since the acid is neutralized by the organism's buffer systems soon after the burn, it should evidently be assumed that the spread of cell damage and development of a secondary zone of paranecrosis are associated with disturbances of metabolic processes and the action of toxic products accumulated in the cornea following an acid burn.

The acid anions react with the protein molecule and form anion-protein complexes. The altered protein molecule carrying a new chemical group acquires new biological properties, including those of antigenic character. Thus, the primary lesion of the cornea caused by the effect of an acid has a number of characteristic signs. On contacting the tissue the acid damages the cells and by changing the pH of the inner medium, leads to acid denaturation of proteins which may be accomplished in two ways: the anion

is incorporated into the molecule, or the spatial structure of the molecule is changed. The dehydration effect of the acid and the disturbed condition of the colloids also lead to cell damage. With a sufficient concentration of an acid cell destruction is instantaneous. Owing to the formation of a ridge of coagulated proteins the acid does not penetrate deep into the tissue layers. The zone of paranecrosis expands and deepens, however, and metabolic processes are disturbed. Direct injury to the corneal tissue advances the development of the process. Denatured proteins and the products of their disintegration are stored and accumulated in the damaged cornea, promoting further development of burn injury and also metabolic disturbances in the tissue.

**Alkaline burn.** The direct burning action of an alkali consists in the following. Alkaline solutions saponifying fats and fatty substances of the cell membranes penetrate the body of the cell, change pH of the cell substance, lead to dissolving (colliquation) of proteins, kill the cell and may penetrate deep into the tissue. In a severe eye burn the damage to the cornea and conjunctiva is attended by a process which also involves the inner coats of the eye, possibly leading to total destruction of the tissues of the anterior eye segment.

Tissue penetrability varies with the alkali. After instillation of ammonium hydroxide into the rabbit's eye its traces are detected in the aqueous humour five seconds later, and thirty seconds later can already be determined quantitatively. According to some authors, this reaction in the humour of the anterior chamber lasts for ten minutes. Berezinskaya (1940) found that an alkaline reaction in the humour of the anterior chamber develops five seconds after instillation of a sodium hydroxide solution, and disappears in 30 minutes. She succeeded in establishing a definite dependence of the speed, with which the alkaline reaction was manifested in the humour of the anterior chamber, on the concentration. An alkaline solution of a concentration ranging between 0.4 and 2 per cent did not alkalize the aqueous humour, a 3 per cent solution produced a weakly positive reaction, while a 5 per cent and higher concentration alkalized it.

A heated alkaline solution penetrated faster and at a lower concentration (Duke-Elder, 1954). At pH 11.0 or 11.2 alkalis cause severe damage to the tissues, the severity

of the damage increasing with the rise of pH (Friedenwald *et al.*, 1946).

In eye burns by various alkalis the type of injury is the same. The difference is only in the speed of the development of the damage and its intensity.

Among alkaline burns of the eye those caused by calcium hydroxide [$Ca(OH)_2$] are most commonly encountered. In the opinion of many authors, the Ca'' cation has a particular affinity with the corneal proteins in distinction to other cations, and its damaging action is therefore not limited to solving proteins; the Ca'' ion damages tissue additionally reacting with the proteins of the cornea and forming Ca-albuminates and Ca-collagenates. The presence of this reaction is proved by the appearance of calcification foci in the cornea.

A burn of the ocular tissues by alkali may also occur when salts of strong bases and weak acids, such as sodium bicarbonate ($NaHCO_3$, $Na_2CO_3$), potash ($K_2CO_3$), etc., get into the eye.

These salts dissociate in aqueous solutions (including tears) forming ions of the base and a weak acid residue. The ions of alkaline metals combining with the remnants of water molecules again form alkali, in other words, burns caused by sodium bicarbonate or carbonate are, in essence, burns caused by a sodium alkali; the same phenomenon occurs when sodium silicate gets in the eye. Practically half of the atoms dissociate then and an alkali is formed which is the burning factor in cases when silicate glue gets into the eye.

Many researchers (Vinogorov and Kopit, 1936; Puchkovskaya *et al.*, 1959; Hughes, 1946; Klima, 1952, and others) conducted histomorphological studies immediately after an alkaline burn of the cornea. Heinc (1969) studied changes in the cornea by ultramicroscopy. The data of all authors testify to the fact that epithelial cells actually die immediately after an alkaline burn. In the first three minutes the nuclei of the epithelial cells are displaced upward, after which desquamation of all epithelial layers occurs. At the same time the stroma swells, its cells undergo fragmentation and disappear, which disturbs the synthesis of polysaccharides. Depolymerization and hydration of acid mucopolysaccharides develop, resulting in disorganization of collagenous fibres. Cell infiltration develops in six

hours and then vascularization may begin because the grounds for it have been prepared by disorders in the stroma (Kaplunovich, 1968; Pfister *et al.*, 1971).

Muchnik (1959) presented the dynamics of the histophysiological features of the process developing in the cornea as the result of an alkaline burn (30 second exposure to a 5 and 10 per cent ammonium solution). His study showed that an eye burn caused by a 5 per cent ammonium solution leads to necrosis of the epithelial cells, and a paranecrotic condition of the cells of the endothelium and stroma. Immediately after the removal of the acting agent (in 10 minutes) and then at later periods (in 1, 3 and 24 hours) the process was seen to advance with an increase in the zone and depth of paranecrotic changes in the cells. In a burn by a 10 per cent ammonium solution, the cells of all the corneal layers are very rapidly involved in paranecrosis. Restoration of the defence function is not observed for fifteen days. This results in irreversible damage to the corneal cells.

The alkaline albuminate into which the protein molecules are transformed after being exposed to the alkali is a compound of proteins with a base. Simpler compounds form in addition, disintegration products of the protein molecule—mercaptans and its larger fragments (phenol, skatole, indole, albumoses, peptones, etc.) (Vinogorov and Kopit, 1936) possessing marked toxicity. They cause dilation of vessels, change the endothelium and give rise to exudation.

The level of vitally important and biochemically active components and reserve substances of the corneal cells like glycogen, ascorbic acid, riboflavin, etc. is sharply reduced (Blinova *et al.*, 1961; Kaplunovich, 1968). The function of respiration is also reduced immediately after the burn.

Alkalis cause protein racemization and change the spatial structure of molecules. Disturbances in the structure of a protein molecule alter its biological properties and may result in changes of its antigenic characteristics.

The direct effect of alkali on the corneal tissue is marked by certain peculiarities, the main one being the ability of alkalis to saponify substances comprising the cell membranes, and thus penetrate the cell, with a shift of the cell pH toward alkali. The dissolution of protein molecules leads to the accumulation in the damaged tissue

of their fragments which have high biological activity. The damaging effect of an alkali naturally depends on its concentration. With high concentration the alkaline solution rapidly penetrates the eye tissue and even the cavity of the eyeball. Under the influence of certain concentrations of alkaline solutions metabolism in the cornea is disturbed and toxic products and proteins with an auto-antigenic characteristics are accumulated in it. Thus, in the first stage of the direct damaging effect there are pathological disturbances, which determine the further development of the process.

We have discussed the typical features of the most common aetiological groups of eye burns which result from the direct interaction of damaging substances with the biochemical components of corneal cells. Various types of chemical reactions occur. The difference consists in the mechanism of damage to the protein molecules, in the specific character of their denaturation. The various mechanisms react and their action in neutralizing acids and alkalis, which penetrate the cells, is always extremely vigorous and distinctive (Sallai *et al.*, 1970).

All the described agents causing eye burns differ in the mechanism of their action, but very soon, in a matter of a few hours the burn damage to the cornea begins losing its individual distinctive features more and more.

Duke-Elder (1954) stressed, that despite the marked difference in the mechanism of damage to the eye tissues caused by various agents, the clinical picture of the process is similar in most cases and depends more on the intensity of the damage. The evidence of this are the results of later studies (Marujama *et al.*, 1968; Pfister, 1971).

Whatever the specificity of protein denaturation by various damaging agents, in the long run it will terminate either in molecule destruction with formation of disintegration products, or the occurrence of a new antigenic specificity of proteins, not inherent in native molecules, i.e. the formation of auto-antigens. Metabolic disturbances in the eye tissues, particularly in the cornea, should be of a similar type, since they are mainly determined by the death of cells in which the processes of metabolism are accomplished. The distinctions, if at all, are quantitative and not qualitative.

## DEVELOPMENT OF THE MAIN LINKS OF THE BURN PROCESS

In speaking of the main links of the process of a burn we have in mind those aspects of its pathogenesis which determine the formation of characteristic clinical signs of eye burn disease and are inherent in it, irrespective of the aetiology of the burn. The typical manifestations of eye burns are as follows.

1. The progressive character of the burn process, which determines expansion of the zone of cell damage, when the damaging agent has either been removed or rendered harmless. It may be the consequence of metabolic disturbances in the eye tissues after the burn, as well as that of the formation of toxic products causing secondary tissue damage.

2. The tendency of the inflammatory process to recurrences, which may sometimes complicate the development of the disease and its outcome, and at times may occur at a remote period after the burn.

3. The tendency toward intensive vascularization of the cornea, the formation of adhesions, proliferation of the conjunctiva and its spreading over the cornea like a false pannus.

4. The dependence of the severity of the burn disease not only on the intensity of the primary damage, but also on certain endogenous factors. This is vividly illustrated in experiments with strictly dosed burns of the cornea. In some animals the burn process may be marked by both the augmentation of the inflammatory reaction and a relatively mild course and favourable outcome. Clinicians have to deal with similar situations and they know from the experience that it is impossible to prognosticate the course and outcome of the process on the strength of the initial picture of the burn damage (Polyak, 1957; Puchkovskaya, et *al.* 1962).

5. A peculiar reaction of the burnt eye tissues to surgical intervention: transplantation of autologous oral mucosa in place of the removed necrotized conjunctiva on the 4th to 6th day after the burn or later may cause a severe reaction drastically complicating the process, whereas such an operation carried out in the first days, or even hours, after the burn may have a therapeutic effect. The eye may also produce a sharp reaction in homoplastic transplanta-

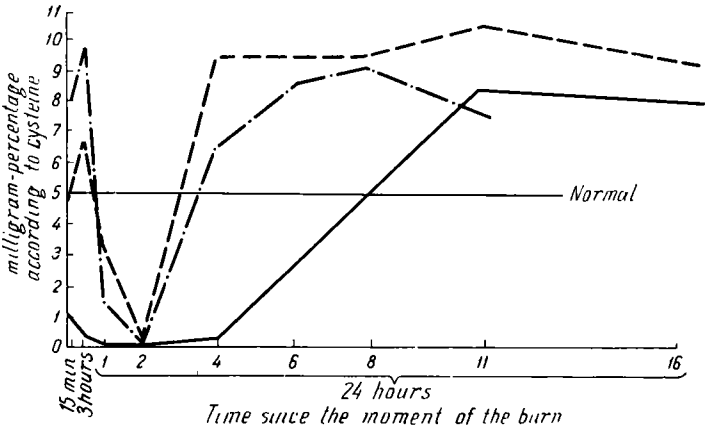


FIG. 1. Changes in the content of sulph-hydryl groups in the cornea of a burned eye during the burn process. Expressed in milligram-percentage according to cysteine. Dash-line indicates burn by molten metal; continuous line burn by ammonium; dash-dotted line burn by sulphuric acid.

tion of the cornea for removing a burn leucoma even many years after the burn.

The disturbed reactivity of the organism developing as a consequence of a burn serves as the pathogenetic foundation for the above stated clinical manifestations of the eye burn disease; its essence and character will be clarified below.

The question arises as to when the aetiological characteristics of the primary damage are effected and the development of the main links of the burn process comes to the fore. As we have seen, in burns of various aetiology specific protein denaturation occurs, which may be revealed according to the condition of the SH-groups.

In fact, the position of the SH-groups in the protein molecule following acid and thermal burns proved to be different than in burns caused by ammonium solution (Fig. 1). The curves in Fig. 1 demonstrate various reactions of these groups following burns of different aetiology. The individual character of these curves may be noted during two to four days. We accept this time conditionally as the period during which the direct damaging effect of various

factors on the cornea is manifest. The direction of the curves then changes, which is associated with the subsequent reaction of the tissues to the burn, in which the effect of the primary damage has no specific reflection. The same duration of the primary damage is revealed in studying the dynamics of the disturbance in the function of general dehydration in the retina of the burnt eye. If we allow that the result of the direct damaging effect of the burning factors is manifested in the primary suppression of the dehydrogenases of the retina while the subsequent increase of their activity is a consequence of the developing secondary mechanisms of the reaction to the burn, then the period of the direct suppression of the dehydrogenase enzymes of the retina in thermal burns of the cornea is limited to 24 hours, and the primary damaging action of an ammonium or acid solution is prolonged to approximately four days.

### THE ROLE OF METABOLIC DISTURBANCES IN THE CORNEA IN THE PATHOGENESIS OF EYE BURNS

In response to the direct damaging effect of scorching substances metabolic changes develop in the cornea. At a later period of the burn process they become more profound and, according to most contemporary ophthalmologists, become one of the most responsible links in the pathogenesis of the process. This point of view seems sufficiently grounded if we take into account the peculiarities of the metabolic processes in the cornea, the leading role of epithelial cells in them, and, at the same time, the exceptional vulnerability of these cells to scorching substances. The danger of disturbed trophic processes in the cornea after a burn increases due to injury to the vessels. Many researchers (Denig, 1912; Miller, 1933; Ochapovskaya, 1946; Pavlyuchenko, 1956, 1958; Kaplunovich, 1969; Kononova, 1968; Puchkovskaya and Nepomyashchaya, 1969) consider that the exclusion of the peripheral looped network due to necrosis or thrombosis of its vessels is a major cause of metabolic disturbances in the cornea. In the opinion of Klima (1963), however, the role of the perilimbal looped network is exaggerated and the secretion of the ciliary body is foremost in the nutrition of the cornea. In a series of experiments Kaplunovich (1968) showed the significance of the uveal tract in the development of the burn process in the

eye more precisely. He established that a burn of the surface layer or even of a deeper row of vessels of the peripheral looped network on a limited area has no substantial effect on the transparency of the cornea, although some indices of its physiological state deteriorate in such cases. Total involvement of the perilimbal network results in the development of marked trophic changes in the cornea. Kaplunovich (1969) concluded that damage to the anastomoses between the anterior and posterior ciliary arteries and disturbances in ciliary blood supply play a significant role in trophic disturbances of the cornea.

Tartakovskaya (1968) described the character of the reaction to the burn process of the perilimbal network and also the vessels of the iris and ciliary body. She claimed that the degree of this reaction depended on the severity of the burn. According to Poltinnikov (1964) and Tartakovskaya (1968), atonic paresis, dilatation and stasis of the capillaries and thrombosis of their lumina develop in the vessels of the perilimbal network as a consequence of a burn. In severe burns dilatation of the lumina of the vessels, their repletion with blood, thromboses and haemorrhages are also found in the iris and ciliary body (Tartakovskaya, 1968). A great role in the trophics of the cornea is also attached to the nerve plexuses of the cornea and conjunctiva, and to the intrascleral nerve plexuses of the eyeball (Ochapovskaya, 1946; Kaznelson and Saushkina, 1950; Shershevskaya, 1959; Isaeva, 1960; Kaplunovich, 1964; Voino-Yasenetsky and Golovchenko, 1970). It is assumed that involvement of the peripheral nervous system in the burn process seriously influences the development of the inflammatory reaction of the eye to the burn. Tartakovskaya (1970) attributes the peculiarities in the development of the burn process to affection of the nerve plexuses in the cornea. A network of nerve fibres is located in the stroma among which are branches of vegetative nerves regulating the trophic processes. Tartakovskaya holds the view that the destruction of these branches may lead to the most severe tissue disturbances and cause long-term, even chronic, inflammatory process.

Many Soviet and foreign ophthalmologists concentrated their research into the pathogenesis of the burn process on the study of the damage to corneal metabolism in burns. In this regard mention should be made of the works of

Kaznelson and his co-workers, which initiated the study of functionally active biochemical substances in the cornea after a burn.

Day (1947), Chernova (1964), Kaplunovich (1968) and others studied the content of glycogen as the main source of energy reserves in the corneal tissues. They established that in burns of various aetiology and degree of severity the amount of glycogen diminished till it vanished completely. It is restored parallel to corneal epithelization and, at the peak of vascularization, its amount may exceed that existing in normal tissue. The function of oxygen absorption changes just as sharply (Chernova, 1964, 1969; Kaplunovich, 1964, 1969). Functional absorption of oxygen by the corneal tissue is reduced by 50 to 70 per cent after a burn as compared to normal. According to Kaplunovich, in severe burns the coefficient of oxygen absorption does not increase till the 27th to 36th day, after which it is activated although remains short of the norm. Chernova found that the level of corneal respiration was restored after the fourth week. The discrepancy in the activity of respiration is stipulated by the different severity of the burn trauma, which is the factor determining the difference in time when epithelization and vascularization of the cornea begin. Kaplunovich's finding is of considerable interest testifying that even in total, particularly severe alkaline burn of the cornea, during the first six to nine days preserved tissue respiration can nonetheless be detected, although its level is extremely low.

Kaznelson and Saushkina (1950) noticed changes in the contents of vitamin C and riboflavin in the corneal tissue after a burn. It was found that the decrease in these vitamins was connected with the destruction of the corneal epithelium (Kaznelson and Saushkina, 1950; Kaplunovich, 1968). Campbell *et al.* (1950) share the view that ascorbic acid plays a considerable role in the burn process. They found that in animals with vitamin C deficiency inflammation after a burn developed less vigorously than in normal animals.

Corneal swelling is typical of the first hours of an inflammatory process caused by a burn. Puchkovskaya *et al.* (1970) conducted investigations in this direction using original techniques. The swelling develops as a direct consequence of damage to the borderline membranes (epi-

thelial and endothelial covers) and causes increased absorption of water by the corneal mucoids from the aqueous humour of the anterior chamber. A definite role in the swelling of the stroma is played by tissue acidosis developing due to inhibited respiration (Tartakovskaya, 1968). In turn, swelling, the hydration of the mucoids, leads to their depolymerization. At the same time, the function of mucopolysaccharides in the cornea is exceptionally important and their loss by the stroma results in profound disturbances in the structure and physiology of tissues. According to Kaplunovich, depolymerization of mucopolysaccharides which began after the burn, increases to the stage of cicatrization when, as he puts it, hardly distinguishable signs of their synthesis are outlined.

Tartakovskaya (1965) claims that disturbances occurring in the stroma after a burn may result in the death of the keratoblasts, the function of which is to reproduce components of the stroma—acid polysaccharides (keratosulphates) specific for organs (Tartakovskaya, 1970).

On the basis of the results of clinical and biochemical investigation, Kaznelson (1961) proposed a pathogenetic classification of the burn process, which consists of four stages.

The first stage following directly after the burn is characterized by necrobiosis, necrosis of the cornea and conjunctiva, damage to the nutrient-supply vessels, swelling and other manifestations of inflammatory reaction. Sometimes an intercurrent infection is actively manifest in this period.

The second stage is that of trophic disturbances and is characterized by completed demarcation of non-viable conjunctival tissues with subsequent regeneration or development of granulation tissue and progressive trophic changes in the cornea. It is with this stage, beginning from the 6th to 9th day after the burn and lasting till the end of the 2nd to 4th week, that the main biochemical changes stipulating the development of subsequent stages are linked.

The third stage, also marked by trophic changes, which, however, are attended by now more, now less vascularization, is called the stage of vascularization.

In the fourth stage that of cicatrization the burn disease terminates and its residual phenomena and sequelae become manifest.

In investigating the condition of the stroma in severe burn of the cornea by sulphuric acid, Tartakovskaya (1969)

compared the disorders found in this tissue with Kaznelson's pathogenetic classification (1961).

Stage I is characterized by necrobiosis of the stroma of the burnt tissues and may be regarded as the stage of dissociation of the protein-polysaccharide complexes.

Stage II, the stage of pronounced trophic disturbances, and stage III, that of vascularization, are marked by deep disorganization of the collagen in the stroma and accumulation of mucoproteins of plasma origin.

Stage IV, the stage of cicatrization, is characterized by an increase in the amount of collagen proteins due to their increased synthesis by the corneal cells which, however, does not produce a normal condition of the stroma.

It should be emphasized that new works have recently appeared in which other biochemical components of the cornea are studied from the standpoint of their participation in the pathogenesis of burns.

Brown and Weller (1970) and Anderson (1971) studied the role of enzyme collagenase in corneal destructive processes and concluded that it contributes considerably to the pathogenesis of corneal ulceration after a burn.

Pfister *et al.* (1971) studied metabolism and the histological picture in the tissues of the anterior segment of a rabbit's eye after alkaline burns and also concluded that correlation exists between morphological changes and metabolic disturbances.

The results of these investigations of the disturbances in the chemical state of the cornea, as well as of those in several functions of the tissue after a burn, show the development of destructive processes in the cornea. They do not, however, explain certain peculiarities in the development of the eye burn disease. First of all, the causes of disturbances in the organism's reactivity and the development of increased sensitivity of the eye tissues remain unclarified, in other words, the causes for the progressive character of inflammation are not disclosed, although the data obtained may indirectly explain them.

### THE ROLE OF AUTO-INTOXICATION IN THE DEVELOPMENT OF THE BURN PROCESS IN THE EYES

It is our opinion that the essence of the next basic link in the pathogenesis of eye burns is the organism's intoxication due to the accumulation of disintegration products

in the burnt tissue and their effect both on the eye tissues and on the whole organism. To confirm the role of autointoxication in the development of the burn process, we performed experiments on rabbits. Under local anaesthesia of the animal's eye we produced either a thermal burn of the cornea or a burn by acid or alkaline solutions.

Toxic products are usually detected by biological tests and also by studying certain biochemical indices, the level of which changes under the effect of intoxication processes in the organism. The indices of oxidation-reduction processes in its various systems change in intoxication. We determined the activity of enzymes of general dehydration in various tissues (in tissues of the liver, skeletal muscles, cardiac muscles and brain, and also of the retina of the burnt and intact eyes) in rabbits with experimentally induced burns. The analysis of this research testifies to the reliability of the obtained results. Dehydrogenase activity in eye burns was suppressed in all tissues examined. In burns caused by ammonium and sulphuric acid, however, the authenticity of suppression of this function was expressed more distinctly and was observed over a longer period of time. In burns by molten metal, however, the changes were reliable only for one or two days after the burn. The balance of oxidized and reduced forms of glutathione was disturbed, evidencing that the burn process in the eye was attended by intoxication. This was likewise confirmed in the study of hepatic secretion.

These data demonstrate the reliable reduction of oxidative processes in these tissues after a burn.

We investigated the activity of substances stored in the burnt corneal tissue in two biological tests. The local action on eye tissues was studied by intracorneal injection to rabbits of a homologous aqueous-salt extract of burnt cornea. The same extract was injected intravenously into guinea pigs once in 4 to 5 days to study its general effect. The extract was prepared from the rabbits' corneas on the 2nd to 4th day after the burn. Standard extracts were produced according to the content of protein (30 mg/100ml).

Intravenous injections of 1 ml of an extract of the rabbits' burnt corneal tissue made once in four or five days at first caused loss of weight and worsened their outward appearance; after the third or fourth injection most of the animals died. It is essential to note that extracts from

corneas exposed to burns of various aetiology had a similar effect. An extract of corneas of intact rabbits' eyes had no such a biological action.

The results of the experiments show that an extract of a burnt cornea has both a local irritating effect on the intact tissue of a homologous cornea and a general toxic effect. In the experiment described it was manifest in the irritating effect on the cornea in local application, and in the death of most animals following intravenous injection. It should be noted, however, that Ushakov's (1968) research failed to confirm the presence of toxic products in the burnt cornea.

Other authors have also described the general toxic influence of a burn process in the eye on the organism. Isaeva and Milstein (1964) reported the disturbances of carbohydrate metabolism in a severe isolated burn of one eye. The glycaemic curve of sugar load demonstrates an increase in the blood sugar content, moreover, very clear-cut disturbances coincide with the destructive processes in the eye after a burn.

In 1937 Protopopov showed that in the burn of one eye biochemical indices of the aqueous humour in the other eye are disturbed. Zats (1959) noted changes in the function of the retina of the healthy eye when the other one was injured. Zhinkin and Korsakov (1951) observed a histomorphological reaction of the corneal epithelium of an intact eye to a burn of the second eye. Vinogorov and Kopit (1936) showed that a severe alkaline burn of the eye is marked by a shift in the differential white blood count.

The discovery of toxic products in the burnt corneal tissue that have an injurious effect both on the surrounding tissues and the whole organism, and also the disclosure of biochemical and physiological disturbances in various organs of animals with an isolated burn of one eye, are important in principle. They testify that certain systems are involved in the pathological process caused by a local burn and, hence, the process developing in a burn should be regarded as a peculiar manifestation of a general burn disease. The eye burn disease and the burn disease developing in burns of the skin and mucosa have common features. Thus, Oppel (1961) states that following a burn the amount of collagen in the rabbits' skin diminishes. In the burnt area collagen loses its capacity for binding water, the frac-

tion of water-soluble collagen decreases and denaturation of the skin collagenous systems sets in. Noting all these disorders, the author mentions Pirie's (1946) research which demonstrated analogous changes of collagen in the cornea in eye burns. Intensive glycogenolysis, which is a consequence of oxygen insufficiency, is observed and anaerobic breakdown of carbohydrates is activated primarily in the affected tissue and near the lesion (Allgöwer and Siegrist, 1957). A similar process in the cornea is described by Chernova (1967) and Kaplunovich (1968). The oxidation-reduction processes are substantially impaired in skin burns. The blocking of the reactive groups in the protein enzyme-carrier leads to disturbances in many processes, including the oxidation function. We have described similar results (Shulgina, 1959).

Vitamin deficiency develops in the burnt skin area just as in the whole organism (Kozdoba, 1942; Sewitt, 1957, and others). Similar phenomena have been noted in the study of vitamins in a burnt cornea (Kaznelson *et al.*, 1961).

The cited facts of metabolic changes, and also the data on disturbances in physiological functions of internal organs in skin burns, characterize the toxic phase of the burn disease.

The primary disorders in biochemical processes of the skin after a burn, as it proceeds from the aforesaid, are similar to those which are encountered in corneal burns. The toxic substances forming in the burnt skin and cornea possess similar features of biological effect. The histophysiological peculiarities of these tissues are different, which brings about their different sensitivity to the scorching substance and, consequently, different forms of clinical manifestation of the burn disease.

We believe that the next fundamental link in the pathogenesis of the burn disease is organism's autosensitization, the source of which are the products of the damaged eye tissues.

### THE ROLE OF AUTOSENSITIZATION IN THE DEVELOPMENT OF THE BURN PROCESS IN THE EYES

Schütz (1936) proved that in skin burns the organism is sensitized by its own proteins. He thinks that one of the first proofs of autosensitization is the disturbed organism's

reactivity that ensures a different course in different individuals of a precisely dosed burn received by the skin. This led Schütz to conclude that the degree of the burn depends not only on the extent and depth of the lesion, but on the organism's reactivity as well. [It should be recalled that experienced ophthalmologists consider it impossible to prognosticate the course and outcome of a burn process at its start. Ochapovskaya (1947) holds the opinion that 'it is not only difficult to establish the depth of the lesion, but simply impossible to assess the tissues' reactivity.]

Of special interest for studying autosensitization and the role of immune reactions after a skin burn are a series of works by Fedorov et al. (1955-61), Skurkovich (1956, 1959), Kolker (1970) and others, which established highly important facts pertaining to the formation of auto-antigens in the burnt skin and antitoxic auto-antibodies produced in response reaction. To clarify the possibility of creating an immunological conflict as a consequence of eye burns, it is necessary to define the following factors in accordance with current views on the conditions of the origin of auto-antigens.

1. Does the biochemical structure of the cornea in normal conditions possess marked organ specificity? It proceeds from the concepts of modern immunologists that marked organ specificity of tissue proteins in certain pathological conditions and their intensified supply into circulation (due to trauma or other pathological condition) proves to be sufficient for producing autosensitization not only to changed proteins, but also to proteins of a normal tissue.

2. Do corneal proteins acquire auto-antigenic properties during denaturation? In this case the antigenic characteristics of tissue proteins after a burn should deviate from the normal.

3. Is the state of autosensitization manifest in animals with an isolated corneal burn?

Special research showed that corneal proteins have marked organ specificity (Shulgina, 1959). In treatment of the cornea with certain substances, the denaturation of its proteins determines the intensified activity of antigenic properties. Thus, Voino-Yasenetsky (1956, 1961, 1962), Merte (1957), Sterger (1961) noted increased antigenic activity of proteins in a cornea treated with formalin. Along

with an increased allergic reaction to transplantation of denatured heterologous corneal tissue, Merte also observed a reaction to formalized autologous corneal tissue, the transplantation of which under normal conditions does not excite a reaction; all this is evidence of the origin of the auto-antigenic function of proteins.

According to Gostev's definition (1959), denaturation of proteins in the broad sense imparts to them new antigenic characteristics. The concept of 'denaturation' itself is used to define even minimal disturbances of the structure or composition of the protein molecule. Profound disturbances, i.e. total denaturation, results in the loss of the native properties of a protein molecule, and, simultaneously, loss of the antigenic function.

It proved possible to clear up the problem of alteration of the antigenic characteristics of the proteins in burnt corneal tissue as compared to that of an intact cornea by using the method of sensitization-desensitization offered by Bezredka-Zilberg (Zilberg, 1958). It was established that a burn of any aetiology confers new antigenic properties to the proteins of the burnt cornea (Shulgina, 1959). Krivenkov and Dzhaliashvili (1965) found that the antigenic specificity of conjunctival proteins changed after a burn. The small surface of the lesion, however (an isolated corneal burn is possible), and the avascular corneal tissue provide special conditions and call for special proof of the possibility that sensitization in eye burns develops. To solve the question on the development of autosensitization in a corneal burn it proved most expedient to employ the Prausnitz-Kuestner skin-allergic test and the reaction of passive anaphylaxis (Kartamyshev, 1948). The skin-allergic test employing rabbit blood serum collected in the third or fourth week after one eye had been burned by a solution of sulphuric acid, ammonium and methyl violet (an aniline dye) showed sensitization of the animals. It was proved that the blood serum contained 'reagins' capable of becoming attached to the skin cells of a healthy rabbit following their intracutaneous introduction, and transmitting to them the increased immunological sensitivity to substances which had caused the development of the burn process. The authenticity of its difference from the reaction to the control serum was high ($P<0.02$).

The state of increased sensitivity may also be revealed

by means of the passive anaphylaxis test. The principle of the method is based on the fact that the state of sensitization can be transmitted to a test animal through the blood serum of the individual under the test, which can then be demonstrated by the reacting injection. Guinea pigs are commonly used as the test animals. The use of the passive-anaphylaxis test in our research showed that guinea pigs could tolerate increased sensitivity to a corneal extract when they were injected with the serum of rabbits suffering from severe eye burns. Guinea pigs of the control group, i.e. those which had received injections of the blood serum of healthy rabbits, did not produce an anaphylaxis reaction to the reacting injection of an extract of a healthy or burnt cornea. At the same time it was observed that the blood serum of rabbits with burns transmits the state of passive anaphylaxis not only to the extract of a burnt cornea, but also to the protein extract of a normal cornea. It should be noted that Miller (1933) described a similar fact; he denatured protein with acids, formaldehyde and other substances and found that an organism sensitized with such denatured protein molecules was sensitive to native proteins as well.

These experiments with passive anaphylaxis and the application of the Prausnitz-Kuestner skin tests are evidence of the fact that autosensitization develops under the effect of an eye burn.

The phenomenon of increased sensitivity can be demonstrated not only in the passive transmission of antibodies, but also on the organism of an animal with an eye burn. To reveal the changed sensitivity to corneal proteins in rabbits, which had suffered eye burns, the reaction of their intact eyes to intracorneal injection of a homologous corneal extract was tested. The experiment was conducted 2 or 2.5 months after the burn of one eye with a 20 per cent sulphuric acid solution. By that time the process in the burnt eye had for the most part stabilized and vast vascular leucomas had formed as a result. The reaction of the experimental rabbits was very typical and differed from that of the control animals. For seven-eight days after injection of the corneal extract the appearance of the eye was normal, but after that an inflammatory reaction set in and Wessely's allergic keratitis developed. Such a reaction had never developed in the control animals (which had not

been subjected to a burn of the contralateral eye before the test) following injection of a homologous protein extract from the cornea.

Research results showed an authentic difference in the reactions of the control and experimental animals. These experiments demonstrated increased sensitivity (sensitization) of the organism of an animal which had suffered from the burn of one eye to corneal proteins, and reproduced a model of the eye reaction to the transplant, the role of which was conditionally enacted in the experiment by a protein extract injected into the cornea.

We have thus gained proof that autosensitization develops after an eye burn and showed, on an experimental model, the immunological essence of the increased reaction to corneal proteins following corneal homoplasty in burn leucomas.

Research showed that the organism's autosensitization is possible as a result of eye burns of various aetiology. The prerequisites for it exist (1) due to the organ specificity of corneal proteins, and (2) because of the denaturing effect on the corneal proteins of the scorching factors leading to additional antigenic specificity. We attach much importance in the pathogenesis of the eye burn disease to the development of increased sensitivity both to the denatured corneal proteins and to the native ones. The latter may become the cause for the development of recurrent inflammation for a long time after the burn and of a heightened reaction to a homologous transplant. The initial stages of autosensitization development are mainly provided by the supply of antigens in the form of proteins denatured by the burn and toxic substances occurring as a consequence of the burn.

In assessing the data stated above on the peculiarities of the pathogenesis of eye burns we find that, despite the fact that the mechanisms of primary damage are different, they ultimately lead to monotypic damage of major importance for further development of the burn. The denaturation of proteins is a phenomenon common to all of them, although it is attained by the action of various substances and in different ways. Protein denaturation results in molecule disintegration with the formation of toxic products, the transmitting of new antigenic characteristics to some of the proteins, the production of auto-antigens and death of cells, which, in turn, increases the amount of toxic sub-

stances and chemospecific antigens. As soon as damaged proteins appear, autosensitization and auto-intoxication begin to develop growing with gradual accumulation of auto-antigens and toxins. From the same time on the mechanisms of metabolic processes in the cornea become impaired. Metabolic disturbances are maintained and augmented by deficient blood supply to the ocular tissues, injury to the nerve plexuses and the developing immunological conflict, the role of which is particularly great. This stems from the fact that an auto-immune process underlies certain clinical signs of the eye burn disease, namely, a tendency to the formation of adhesions, development of a false pannus and increased vascularization of the cornea, recurrences of the burn process both in the initial stages of the disease and long afterward. The recurrences of the inflammatory reaction may noticeably complicate the course of the burn process and this is precisely the property which determines the difficulty in prognosticating the course and outcome of the eye burn.

The reaction of the eye to transplantation both of autologous mucosa by Denig's method, and of homologous cornea during the management of the consequences of the burn, are also of immunological nature.

We think that trophic disturbances in the corneal tissues are very closely interconnected with the state of autosensitization and mutually sustain the pathological process. It should be assumed on these grounds that for pathogenetic therapy it would be rational to apply all measures which could normalize trophic processes in the cornea as well as those which might lead to the desensitization of the organism or suppression of its immune reactivity.

CHAPTER II

# Immunotherapy in Eye Burns (Experimental Data)

The significance of various aspects of the pathogenesis of any disease for its development and outcome may be revealed in different ways. One of the most common consists in experimental exclusion of the effect on the pathological process of the factor studied and comparison of the developing process in a group of experimental and control animals. This is precisely the method we selected for assessing the role of autosensitization and auto-intoxication in the pathogenesis of the eye burn disease.

The effect of autosensitization and auto-intoxication could be excluded by using immune sera enriched with antibodies against denatured proteins (antigens and toxins) occurring in a burn. By using the experience of immunotherapy in skin burns (Fedorov, 1961; Skurkovich, 1956) we decided to apply antiburn antitoxic serum for treating eye burns. With a view to apply in the first experiments an immune serum specific in relation to the aetiology of the burn, we treated thermal eye burns with a homologous serum of convalescents from a thermal skin burn, and chemical burns (caused by acid, alkaline and aniline dyes) with serum specially produced in rabbits by their immunization with proteins denatured beforehand by the substances mentioned. After the rabbits had been immunized, the presence of specific antibodies and their titre were determined by means of the precipitin reaction on agar. A sufficient amount of immune serum was prepared for treating burn disease of the corresponding aetiology. For treating eye burns this serum, as well as the burn convalescent serum, was infused intravenously (into the marginal vein of the ear) in a dose of 2.5 to 3.0 ml per kg of body weight; 6.5 to 8.0 ml of the serum were injected respectively in a single

dose. We did not employ supplementary measures, even antibacterial therapy, either in the control, or in the experimental groups of rabbits. The control group consisted of rabbits with a similar eye burn to which homologous blood serum of healthy rabbits was injected intravenously as a therapeutic agent. A special stamp was used to produce a dosaged burn of one third of the corneal surface. Despite the standard method used for inflicting the burn, the different degree of the organism's reactivity determined certain variants of the inflammatory reaction in the eye.

In the control group immediately after a thermal burn produced by a ten-second contact of the cornea with a metal stamp heated to 250°C, the cornea clouded and the epithelium was partly desquamated. A short while afterward the mild opacity caused by swelling spread over the whole cornea. On the second or third day opacity intensified, while the epithelial defect in the burnt area spread and deepened involving the deep corneal layers down to Descemet's membrane. The reaction of the iris was manifested in swelling, dilatation of vessels and a sharp contraction of the pupil. Often an exudate formed in the anterior chamber on the third day. The reaction mounted, hyperaemia and swelling of the eyelid and eye conjunctiva subsequently increased, an abundant purulent discharge from the conjunctival cavity appeared, the amount of exudate and the degree of corneal opacity grew. Vessels appeared in the cornea between the fifth and seventh day of the burn. At first they grew into the cornea only in areas adjoining the focus of affection, and never at the site of the burn. On the contrary, vascularization often seemed to pause not overstepping the boundary of the burnt tissue. Meanwhile, the area of the ulcerated cornea expanded and deepened and sometimes perforated. This was always the case in the presence of an ulcer attended by a relatively mild vascular reaction. Vessels growing into the cornea and rapidly penetrating the site of the burn practically always prevented tissue perforation. Granulation tissue formed on the cornea together with vessels, gradually encircling the zone of ulceration and then covering it. The growing in of vessels and formation of granulations after ulceration and even after perforation of the cornea were vigorous.

Usually, after the 14th to 18th day, the process became somewhat subdued, the connective tissue growths on the

cornea underwent involution and vascularization of the cornea diminished. Due to the diminished hyperaemia and disappearance of swelling, the conjunctiva of the eyelids and eyeball took on an almost normal appearance. A coarse vascular leucoma formed on the greater part of the cornea.

Particular attention was drawn to the rabbits in which the process after the burn was more languid: there was neither vigorous growth of the granulation tissue in the form of a false pannus, nor strong vascularization of the cornea between the fifth and the fourteenth day. The process subsided by the end of the second or beginning of the third week. Quite often, however, an acute reactive inflammation developed in these animals on the 15th to 21st day, displayed by swelling of the cornea and its total opacity, and the sudden increase in the vascular reaction of the conjunctiva of the eyelid and eyeball. This was attended by a vigorous vascularization of the cornea. Such an inflammatory outburst usually subsided within a few days, but at times took a protracted course.

The condition described characterized the course of the inflammatory process in most animals of the control group, with which the condition of eyes of experimental rabbits was compared. Besides the 'average', most typical cases, the control group also had 'extreme' cases with relatively a milder or graver development of the process. The severest cases were marked by disintegration of the eye membranes, and the rabbits died displaying signs of general intoxication; cases with recurrent kerato-uveitis were observed, which lasted more than six months and resulted in subatrophy of the eyes. Confined leucomas developed on the site of the burn in the mildest of cases.

The reaction to eye burns of other aetiology was the same. The concentration of chemical substances which we chose and the exposure to their action produced a more or less uniform character of the course of the process and its outcome.

The control and experimental animals received intravenous injections of serum from the second day after the burn, and then four times every other day.

The development of the process and its outcome in the experimental rabbits had certain characteristic features. The burn took a favourable course as a rule. The peculiarities in the development of the process and its outcome in

the experimental and control groups were compared (Table 1) by the following indices: (1) the time of vascularization of the burnt corneal area; (2) the intensity of connective tissue growth; (3) the frequency of ulceration and perforation of the cornea; (4) recurrences of inflammation; (5) death of animals from intoxication.

*Table 1.*

COMPARISON OF THE PECULIARITIES IN THE PATHOLOGICAL PROCESS IN EYE BURNS OF VARIOUS AETIOLOGY IN EXPERIMENTAL AND CONTROL ANIMALS

| Type of burn | Rabbit group | Number of animals in a group | Early beginning of vascularization (before 8th day) | Corneal perforation | Growth of granulation tissue | Recurrences of inflammation | Death of animals from intoxication |
|---|---|---|---|---|---|---|---|
| Thermal | Control | 22 | 4 | 12 | 12 | 8 | 1 |
| | Experimental | 17 | 12 | 5 | 3 | 0 | 0 |
| Aniline dye | Control | 10 | 0 | 5 | 8 | 0 | 0 |
| | Experimental | 10 | 10 | 1 | 0 | 0 | 0 |
| Ammonium solution | Control | 19 | 6 | 9 | 5 | 0 | 3 |
| | Experimental | 18 | 12 | 1 | 0 | 0 | 0 |
| Sulphuric acid solution | Control | 24 | 9 | 6 | 0 | 8 | 1 |
| | Experimental | 24 | 15 | 1 | 2 | 0 | 0 |

*Note:* Various peculiarities in the pathological process were often encountered in one and the same rabbit.

Table 1 shows that in experimental rabbits irrespective of the aetiology of the burn the use of specific immune serum with a marked antitoxic action ensured the improvement of regenerative processes. Perforation of the cornea was rarer, granulation growths were insignificant, there was not a single case with recurrent inflammation (sensitization phenomenon) or death from intoxication.

The statistical analysis of data obtained in comparing the results of treating animals in the experimental and control groups (Table 2) showed a high degree of authenticity ($P>0.03$).

*Table 2.*

OUTCOME OF INFLAMMATORY PROCESS INDUCED BY EYE BURNS OF VARIOUS AETIOLOGY

| Type of burn | Rabbit group | Number of animals | Outcome | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Loss of eye | Almost total or total cicatricial leucoma | Partial cicatricial leucoma | Superficial opacity | Death of animals from intoxication | Recovery (restoration of transparency) |
| Thermal | Control | 22 | 2 | 13 | 5 | 1 | 1 | — |
| | Experimental | 17 | 0 | 0 | 7 | 7 | 0 | 3 |
| Aniline dye | Control | 10 | 2 | 8 | — | — | 0 | — |
| | Experimental | 10 | 0 | 2 | 2 | 6 | 0 | — |
| Ammonium solution | Control | 19 | 2 | 5 | 5 | 4 | 3 | 0 |
| | Experimental | 18 | — | 1 | 7 | 6 | 0 | 4 |
| Sulphuric acid | Control | 24 | 6 | 10 | 5 | — | 1 | 2 |
| | Experimental | 24 | 1 | 9 | 7 | 4 | 0 | 3 |

In summing up the cited data it should be noted that intravenous infusions of the burn convalescent serum in thermal eye burns, or of specific immune serum in chemical eye burns have a favourable effect on the course and outcome of the inflammatory process. Even after two infusions, processes of regeneration already begin to predominate over those of destruction, corneal swelling diminishes and vascularization occurs much earlier, producing a favourable effect in this period. The corneal tissue appears to be strengthened. The ulcerations are delimited or filled with cicatricial tissue; therefore in the experimental animals late ulceration and perforation of the cornea are observed less frequently.

Under the effect of specific immune serum, the reaction of the iris was also noticeably diminished, exudate in the anterior chamber appeared more rarely, whereas the accumulated exudate was usually rapidly resorbed. The favourable effect of the serum was also seen in the last develop-

mental phase of the process, in the period of cicatrization. Growth of connective tissue over the cornea was frequently observed both among the control and experimental animals, but in the latter the process was less vigorous and involuted rapidly with the result that total and almost total leucomas with growth of cicatricial tissue in experimental animals formed less frequently than in the controls. The serum also produced general antitoxic action preventing animals' death. The data cited show that immune reactions developing in burns are important in the development and outcome of an eye burn. Intravenous injections of specific immune rabbit serum in treating eye burns of a corresponding aetiology have a marked therapeutic effect.

This therapeutic effect obtained in experiments naturally brings up the question of employing immunotherapy in eye burns in the clinic. In order to proceed from experimental research to clinical recommendations, however, it was necessary to provide for a source supplying the corresponding immune serum. In the clinic only homologous serum can be used. In line with the results of experiments, thermal eye burns may be treated in the clinic with blood serum of convalescents who had suffered thermal skin burns. The reality of supplying the clinic with such a serum called for solving the problem of its possible use also for treating chemical eye burns.

The theoretical premise for testing the therapeutic effect of serum not specific with regard to the aetiology of the burn is that even in specific denaturation of proteins of various tissues the disintegration products of protein molecules prove to be of the same type in their antigenic characteristics and possess a similar toxic effect. This gives grounds to presume that an antiburn antitoxic serum of convalescents recovering from thermal skin burn may be used to treat eye burns of any aetiology. The above stated assumptions were tested experimentally on animals with eye burns caused by lime and sulphuric acid.

We shaped the experiment to clinical conditions by administering serum not intravenously, but as subconjunctival injections. This method ensures less waste of the serum, blocking of a delimited burnt area and introducing the antitoxic antiburn antibodies directly to the focus of toxin production. The convalescent serum for treating experimental chemical burns was produced on donor rab-

bits by Skurkovich's method following repeated infliction of thermal skin burns.

The convalescent serum was taken from animal donors after the burn had fully healed and then injected under the conjunctiva in 1-ml doses every other day to a total of no more than ten injections. Injections were begun on the second day after the burn.

The standard burn was caused by Polyak's method (1957). Standard severe burns of the upper half of the cornea were produced by a 25 per cent suspension of freshly slaked lime.

The results of the treatment of a burn process in the eye of experimental rabbits with subconjunctival injections of convalescent serum were compared with the data obtained in three control groups; the first group consisted of animals who received no injections whatsoever; the second group of animals received injections of normal serum; the third group was comprised of animals given subconjunctival injections of blood serum of rabbits with a fresh (developing) burn process in the eye. This last group will be discussed separately. The amount of the serum and the frequency of injections were the same for all groups.

The control groups were intended for revealing certain aspects of the action of convalescent serum. The first group had thus been designated for general recording of the severity of the process caused by the burn and the dynamics of its development. The second control group was used to provide a possibility for comparing the peculiarities in the course and outcomes of a process caused by an eye burn with those of an experimental group so as to differentiate the therapeutic effect of convalescent serum from that of a normal serum. The third control group was needed to clarify the significance of the toxic effect in applying the serum of animals suffering from a fresh severe burn of the eyes.

The inflammatory process in various parts of the eye was assessed according to a five-point system and the data were summed up. This enabled the dynamics of the burn process to be expressed in numbers, which were then presented graphically (Fig. 2).

On comparing the peculiarities of the course of a burn process in experiments and controls, the time of the appearance of the main signs of the burn process and the presence

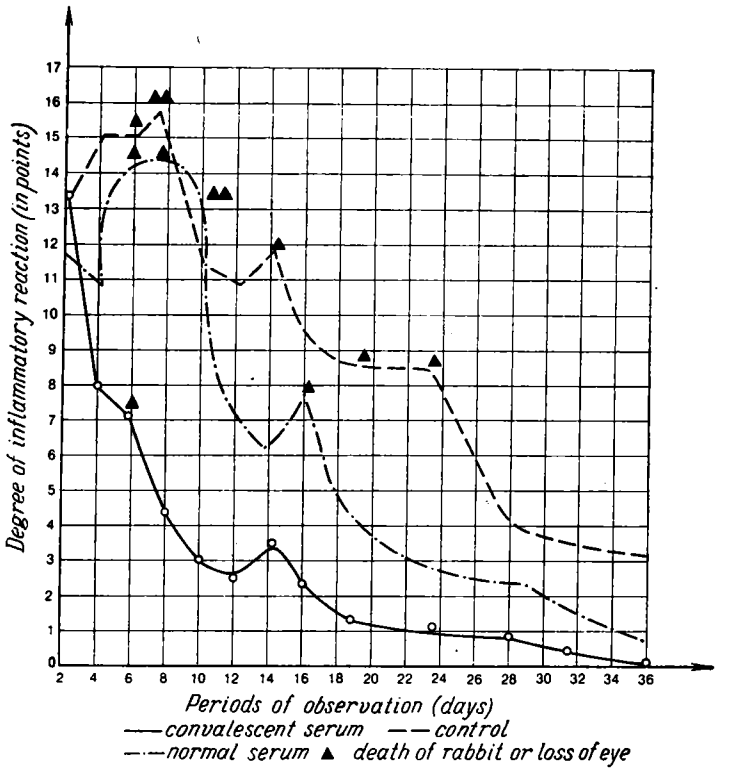


FIG. 2. The dependence of the intensity of an inflammatory reaction on the type of therapy employed (average curves).

of certain complications were recorded; (1) the time needed for completing the inflammatory reaction in the conjunctiva, eyelids and iris; (2) the time of completed epithelization of the cornea; (3) the beginning of corneal vascularization; (4) resorption of the opacities; (5) spread of corneal opacities to intact areas; (6) the presence of such complications as infiltrates and ulcers of the cornea, hypopyon, recurrences of corneal inflammation and erosion.

In the control group the pathological process reached its peak by the sixth to eighth day of the burn (Fig. 2). This was evidently due to intoxication which first involved

the adjacent ocular tissues, and then the whole organism, causing the animal's death in some cases. Subconjunctival injections of aetiologically non-specific antiburn serum of convalescents led to just as obvious an alleviation of the process and changes in the character of its course compared to that in control animals, as it was shown in describing the effect of intravenous infusions of specific immune serum. Animals treated with immune serum showed a significantly reduced degree of the inflammatory reaction from the first days (curve I on the graph has no initial ascent). In the control group (curve II) and in rabbits treated with homologous serum of healthy animals (curve III) the pathological process was monotypical, with marked augmentation of the inflammatory reaction in the first days after the burn, and gradual descent of the curve attended by secondary waves of inflammation.

Comparison of the course of the burn process and its outcomes in three groups of rabbits testifies to the high therapeutic effectiveness of burn convalescent serum in lime injury of the eyes. In comparing the time needed for the disappearance of the main signs of the inflammatory process in these groups (Table 3) we can see that it hardly differs in animals of both control groups, and is authentically different in animals treated with convalescent serum.

*Table 3.*

COMPARATIVE DATA ON THE COURSE OF THE BURN PROCESS IN EXPERIMENTAL AND CONTROL GROUPS AFTER A LIME BURN

| Experimental series (treatment) | Number of animals | Average time, days | | | |
|---|---|---|---|---|---|
| | | Disappearance of main signs of burn process | | | Beginning of corneal vascularization |
| | | Inflammation of eyelids, conjunctiva | Inflammation of iris | Epithelization of cornea, disappearance of erosions | |
| Experimental group (convalescent serum) | 19 | 17.1± m=3.08 | 12.69± m=2.25 | 12.11± m=1.58 | 8.38± m=0.8 |
| First control group (without injections) | 19 | 19.5± m=4.9 | 29.0± m=5.34 | 20.0± m=4.46 | 12.35± m=1.75 |
| Second control group (normal serum) | 19 | 28.7± m=4.51 | 24.46± m=5.03 | 20.29± m=4.32 | 12.55± m=1.9 |

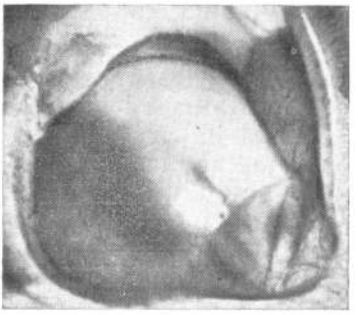

FIG. 3. Rabbit No. 777. A lime burn, the second day (control II).

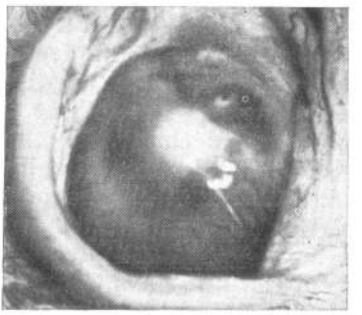

FIG. 4. Rabbit No. 777. One month after the burn. The rabbit has been given ten subconjunctival injections of normal homologous serum. Total vascular leucoma with a corneal ulcer and persisting inflammation.

Injections of normal rabbit serum were conducive to a certain decrease in the number of complications in this group of animals as compared with those not given injections; the results, however, proved much poorer than those in employing convalescent serum. The comparison of the therapeutic results in these groups of rabbits convinces us of the particular value of convalescent serum and significance of its antitoxic effect.

The toxic effect of the necrotic focus is neutralized under the influence of the immune antiburn serum. The process seems to be localized on the site of the initial damage and the inflammatory reaction gradually wanes. By eliminating or alleviating auto-intoxication, the burn convalescent serum augments the regenerative capacities of the ocular tissues, which affects the outcome of the burn.

In biometric processing of the results gained in studying the therapeutic effect of specific immune serum we combined the indices characterizing the outcomes of the process into two groups: (1) those with a favourable effect, and (2) with an unfavourable effect. Partial opacity of the cornea and total restoration of its transparency formed the first group and irreparable changes in the eye and death of rabbits the second. Reliable differences were obtained between the number of animals with a favourable outcome

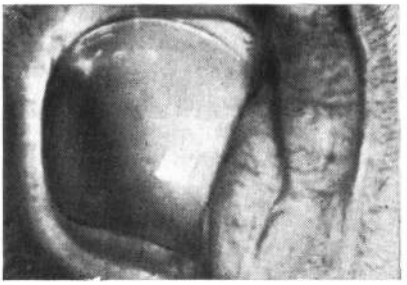

FIG. 5. Rabbit No. 634. Two days after a lime burn (experiment).

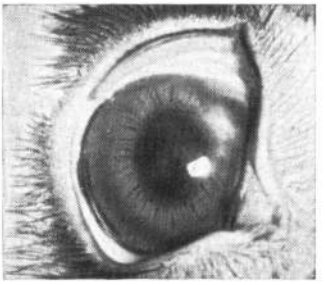

FIG. 6. Rabbit No. 634. One month after the burn. The rabbit has been given ten injections of burn convalescent serum.

in the experimental group as compared with the controls, which is evidence of the marked therapeutic effect of subconjunctival injections of convalescent serum.

Photographs of the rabbits' eyes clearly illustrate the peculiarities in the course of the pathological process and its outcomes in the control group (treated with normal serum) and in the group of experimental rabbits given injections of convalescent serum (Fig. 3-6).

The experimental data obtained testified to the non-specificity (in relation to the aetiological factor) of the therapeutic effect of serum taken from convalescents after a thermal skin burn.

Since the problem of the use of non-specific convalescent serum in burns of various aetiology is very important in clinical practice, additional investigations were undertaken to study the effectiveness of convalescent serum in acid burns which showed its high effectiveness in severe eye burns by sulphuric acid. The data obtained in immunotherapy of eye burns by sulphuric acid were similar to the results cited above and are therefore not discussed in detail.

Rabbits treated by means of subconjunctival injections of homologous serum of animals with fresh eye burns formed a special group. Observations showed that injections

of such serum, far from improving the course of the eye burn disease, can complicate it considerably. Even after the first two or three injections the condition of the eyes grew much worse, necrotic processes in the conjunctiva and cornea intensified, and the iris became involved in the inflammation with seepage of exudate and blood into the anterior chamber. The cornea underwent copious infiltration, necrotized and its opacities spread to unburnt areas. General intoxication of the animals' organism usually simultaneously increased. Table 4 illustrates the results of the observations of this group of animals.

*Table 4.*

COMPARATIVE DATA ON THE COURSE AND OUTCOMES OF LIME EYE BURNS IN CONTROLS AND IN ANIMALS TREATED WITH HOMOLOGOUS BLOOD SERUM OF FRESHLY BURNT ANIMALS

| Treatment | Number of animals | Complications | | | Outcome | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Unfavourable | | Favourable | | |
| | | Hypopyon | Spread of process to intact part of cornea | Ulcers and corneal infiltrates | Death of animal | Loss of eye | Extensive leucoma | Incomplete leucoma | Transparency of cornea |
| Injection of homologous serum of freshly burnt rabbits | 19 | 8 | 15 | 4 | 8 | 2 | 3 | 5 | 1 |
| Controls (without injections) | 18 | 9 | 13 | 4 | 5 | 2 | 2 | 6 | 3 |

As it is seen from Table 4 the unfavourable results were encountered in 13 out of the 19 rabbits comprising this group, which proved, therefore, to be somewhat poorer than in the group where immunotherapy was applied and in the control group where no injections were given.

Data in the literature and our own experience help in the interpretation of these experiments. It is known from publications (Schütz, 1931; Fedorov and Skurkovich, 1955) that injections of blood taken from recently burnt dogs cause certain physiological functional disturbances in healthy dogs corresponding to those developing in the burn disease.

Moreover, to obtain antiburn serum Fedorov and Skurkovich proposed to immunize animals, the future donors, not only by the infliction of burns, but also found it possible to vaccinate them with the serum or blood of dogs which had suffered burns recently. The works of these authors also show the cytotoxic effect on the cells of a haemoculture of a blood admixture of animals which had been recently burnt. This phenomenon was later utilized in the elaboration of tests for revealing antitoxic activity of convalescent serum.

Our experiments (Shulgina, 1960) showed that it was possible to demonstrate the cytotoxic effect on a haemoculture of the serum of animals with a burn of one eye of various aetiology. It was also established that intravenous infusion of blood serum, taken from animals with a fresh burn of the body, inevitably aggravated the course and outcome of a burn process in the eye (in the same way as it was observed in subconjunctival injections of serum of burnt individuals).

The obtained data, testifying to the toxicity of the serum collected from animals with a fresh burn, bespeak the hazard inherent in the use of such serum for the treatment of eye burns. Blood and preparations from it cannot be used for therapeutic purposes until the donors have fully recovered from the burn.

In summing up the results of immunotherapy in experimental chemical eye burns, a conclusion should be made of the high therapeutic effectiveness of serum obtained from burn convalescents, both specific with regard to the aetiology of the burn and non-specific collected from donors who had suffered severe thermal skin burns.

The serum of burn convalescents possesses, in the first place, marked antitoxic properties, which is confirmed by the sharp reduction in the number of complications associated with a burn and earlier restoration of regenerative processes in the eye leading to better outcomes of the burn.

Such serum also has a desensitizing effect, which is reflected in moderate vascularization, relatively weaker development of cicatricial growths, and absence of recurrent inflammation.

The results of experimental study showed that in chemical eye burns it is possible to use serum of convalescents after a thermal skin burn non-specific in relation to the aetiology of the burn. This made the use of immunotherapy in clinical conditions practical and helped to cope with the problem of antiburn serum donors. Last of all, the elaboration of a method for introducing immune serum for treating eye burns is no less significant for clinical practice. It is common knowledge that the presence of a haemato-ophthalmic barrier often compels ophthalmologists to resort to the local administration of the drugs, which proves to be more effective than their introduction into the circulation, and thus to use lower doses with a good therapeutic effect. The injection of antiburn serum under the conjunctiva was effective enough for treating eye burns in which the antitoxic effect of the serum upon the course of the burn was manifested after the first two or three injections.

Thus, the proposed method for treating eye burns with subconjunctival injections of serum obtained from burn convalescents is a simple method accessible both in outpatient and in-patient clinics. It requires a relatively small amount of serum which makes it possible to organize the supply of ophthalmological establishments with it.

Our data has been confirmed by the research of Krasnikov and Malova (1964), Dzhaliashvili and Krivenkov (1965), Krasnikov (1967) and Chernova (1969) who studied the therapeutic effect of burn convalescent serum in eye burns in experiments and in clinical conditions.

CHAPTER III

# Assessment of the Degree of Severity of Burn Damage to Various Parts of the Eye

The elaboration of a standard, generally accepted classification of eye burns is an important task, because it not only provides for the timely and correct assessment of the severity of damage to the eye and prescription of the most rational treatment but enables one to determine its prognosis, and the possibility of subsequent disability of the patient. A single universally recognized conception of the degree of severity of damage to the eye may help to give a reliable estimate of the effectiveness of numerous nonsurgical and surgical measures for treating eye burns and has a major scientific and practical importance.

There are several basic variants of classifications of eye burns according to the severity of damage, which are currently used by ophthalmologists (Ochapovskaya, 1941, 1946; Pavlyuchenko, 1956; Milovidova, 1957; Polyak, 1957; Gassler, 1965, and others).

The most widely accepted classification specifies eye burns according to three degrees of severity, depending on the depth of the affection and localization of the burn (Thies, 1938; Berezinskaya, 1940; Hughes, 1946; Kaznelson and Saushkina, 1950; Milovidova, 1957, and others).

Thies (1938) distinguishes three degrees of burn severity and characterizes the burn damage to the various parts of the eye as follows: in I degree damage to the eyelids there is hyperaemia of the skin; II degree damage is characterized by vesicles and extensive areas of hyperaemia; and III degree damage is marked by necrosis of the skin, which darkens, and a defect in the tissue forms subsequently.

Damage to the eyeball of the I degree is marked by diffuse or localized hyperaemia of the conjunctiva and swelling of the cornea. In II degree marked chemosis of the con-

junctiva develops and opacities of the superficial corneal layers (the corneal tissue proper remains quite transparent, which is seen after the surface layers have been removed). A III degree burn is characterized by necrosis of the conjunctiva; the cornea may be transparent, but usually it is cloudy, opaque, and the pupil is always sharply constricted.

The shortcomings of this classification are that, first, in assessing the severity of the burn the extent of the damage to various parts of the eye is not taken into account; second, in distinguishing the three degrees of severity the picture of corneal damage is not clearly characterized, and the severest injuries to the cornea, conjunctiva and sclera are not defined.

Ochapovskaya (1941, 1946) attempted to consider two basic factors determining the severity of the burn, namely, its depth and extent, and added another three groups (A, B, and C) specifying the extent of the burn, to the three degrees in the classification.

According to Ochapovskaya, a I degree burn is only attended with hyperaemia of the vessels and slight swelling of the tissues. In II degree a deeper inflammatory reaction is noted with involvement of the vascular walls, the development of drastic swelling and destruction of the epithelial covering. In III degree the necrosis of the involved tissues is typical.

According to the extent, Group A includes burns of various degrees not spreading to the limbus and cornea; Group B — burns involving part of the limbus and part of the cornea or only the cornea, but not all of it; Group C — burns of various degrees approaching the limbus from all sides, or involving the entire corneal surface.

As it is seen from the above description, Ochapovskaya's classification also does not reflect the total variety of the clinical symptoms of eye burns. Pavlyuchenko's classification (1956) is more detailed and closer associated with clinical manifestations of eye burns; it distinguishes four groups of severity demarcating severe and very severe burns according to the clinical picture ('opaque glass' and 'porcelain' cornea). Among the shortcomings of this classification are numerous literal designations, disregard of eyelid involvement, and disparity with the commonly accepted groupings of burn severity (for instance, I degree

severity characterizes the severest burns). Polyak's classification (1957) is now the most widely used in the Soviet Union and found to be most convenient for practical use. It takes into account the depth and extent (area) of the burn, thus providing the fullest characteristics of the severity of the eye burn.

Subdividing burns into four degrees, the author takes into account the depth (degree) of the burn, and its extent, and distinguishes four groups of severity: mild, moderate, severe and particularly severe. Polyak's classification allows the severity of the burn of the eyeball (conjunctiva and cornea) and that of the eyelids to be specified separately in the diagnosis if they are different. It fully reflects the clinical symptoms in various degrees of burn and, at the same time, is free of unneeded detailing, which is the disadvantage of several other classifications (Pavlyuchenko, 1956, and others).

It should be emphasized, however, that just as any other classification, which is a conditional scheme grouping burn injuries to the eye, Polyak's classification also has its shortcomings. It determines the severity of the burn, primarily in the initial period of the burn disease, practically neglecting the dynamics of the burn process and possible complications which make the prognosis much worse with regard to preserving the function of vision and the anatomical integrity of the eye.

This classification is also inapplicable in certain burns, which fail to produce a typical picture of the lesion. Ammonium burns, for instance, usually do not cause intensive corneal opacity immediately after the injury, which, in certain cases, leads to the incorrect assessment of the severity of the burn. At the same time, it is precisely these burns which lead to the severest complications and outcomes.

Not only ammonium, but certain other chemical substances (acetic acid, some organic compounds, etc.) causing serious changes in the deep parts of the eye, are attended with severe complications in the very first days after the burn. An ammonium burn of this type is illustrated in Figs. 7 and 8.

In assessing the severity of a burn of that type (on the day it occurred), according to the classification, one can hardly speak of a severe eye burn, to say nothing of a par-

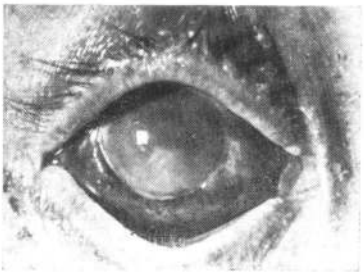

FIG. 7. A particularly severe ammonium burn of the right eye, the fourth day: hyperaemia of the conjunctiva, cornea not intensively opaque, exudate in the anterior chamber, the lens is opaque. Acuity of vision—light perception with incorrect light projection.

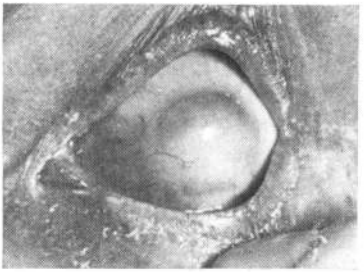

FIG. 8. The outcome of a particularly severe ammonium burn.

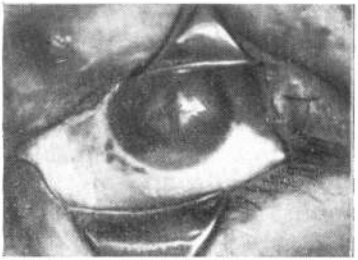

FIG. 9. A particularly severe burn by concentrated acid, the third day. Acuity of vision—light perception with incorrect light projection.

ticularly severe burn, which it actually is. It is these patients, however, that require most urgent aid and care because in the very first days severest complications are apt to develop due to the affected deep parts of the eye.

In the case illustrated in Figs. 7 and 8, despite the relatively favourable picture of the injury to the anterior eye segment, an exudate was found in the anterior chamber on the third or fourth day, which continued to grow, producing a stable increase in intra-ocular pressure. The pro-

cess terminated in the formation of a deep vascularized leucoma, diminished vision to light perception and incorrect light projection.

Our many years' clinical experience has shown that burns attended at the very beginning with such concomitant symptoms as increased intra-ocular pressure, massive exudation into the anterior chamber, marked inflammation in the iris and lens opacity are characterized by the severest course ending in considerable loss of visual functions or even the loss of the eye.

Accepting completely the assessment of the depth of the injury to the tissues of the anterior eye chamber suggested by Polyak (four degrees of a burn in his classification) we consider it expedient, in making a final diagnosis, to consider the early concomitant symptoms listed above, the presence of which reliably indicates the degree of severity of the process.

It would also be expedient to distinguish certain indices in Polyak's classification which characterize damage to the sclera and limbus, and also to introduce such characteristics of the affection of the cornea as a defect and thinning of its tissue over a more or less considerable area, which may occur through instantaneous coagulation and rejection of corneal layers (i.e. in burns by concentrated acid or molten metal with a high melting point).

Table 5 is our extended classification of the severity of eye burn damage in which we included the early attending symptoms manifested no later than the seventh or eighth day after the burn, and which additionally characterize its severity.

Fig. 9 shows the condition of an eye after a criminal, particularly severe burn by a concentrated sulphuric acid. On admission the cornea seemed to be completely transparent, but examination with a slit lamp showed it to be drastically thinned almost down to Descemet's membrane. Elements of the anterior chamber and an opacified lens were seen through the transparent thinned cornea. This condition of the eye developed through rejection of the necrotized layers of the cornea and exposure of its deep layers. The conjunctiva was also separated from the sclera. In this case the burn followed a most severe course and terminated in the formation of total symblepharon and ankyloblepharon, despite careful treatment.

*Table 5.*

CLASSIFICATION OF SEVERITY OF BURN DAMAGE TO THE EYES

| Severity of burn | Degree (depth) of burn | Damage to the anterior | | |
|---|---|---|---|---|
| | | Eyelids | Conjunctiva | Sclera |
| Mild burns | I | Hyperaemia of the skin | Hyperaemia | — |
| Moderate | II | Formation of vesicles | Ischaemia, swelling, superficial films | — |
| Severe | III IV | III degree necrosis of the skin or IV degree lesion of less than half the eyelid | Necrosis of not more than half of the conjunctiva of eyeball | Lesion on area of not more than half the eyeball |
| Particularly severe | IV | Necrosis of the skin and underlying tissues of more than half of the eyelid | Necrosis of conjunctiva of more than half of the eyelid and eyeball | Lesion of more than half of the eyeball |

DEPENDING ON THE DEPTH AND EXTENT OF TISSUE DAMAGE

| segment of the eyes | | Early attending symptoms | | |
|---|---|---|---|---|
| Limbus | Cornea | Intra-ocular pressure | Lesion of iris and ciliary body | Lesion of crystalline lens |
| Hyperaemia | Erosion of cornea, slight swelling of surface layers (slit lamp) | Normal | — | — |
| Short-term ischaemia, hyperaemia | Opacity of anterior layers (non-intensive 'opaque glass') | Normal | Hyperaemia (without exudate) | — |
| Marked ischaemia of vessels over not more than half of the limbus circumference | Deep opacity in all layers (intensive 'opaque glass') or IV degree ('porcelain' cornea) damage to not more than half the area. Tissue (non-perforating) defect of not more than a third of the cornea | Short-term rise or hypotonia | Marked iridocyclitis, exudate filling not more than one third of chamber | — |
| Total ischaemia and thrombosis of vessels | 'Porcelain' cornea extending over more than half of its area: deep tissue defect (thinning) of more than a third of its area | Stable rise | Marked plastic iridocyclitis, exudate filling more than half of the chamber | Opacity |

Thus, the inclusion into clinical classification of early attending symptoms, manifested in the first seven or eight days, allows the more precise definition of the degree of the burn severity, because they are convincing evidence of involvement in the process of the deep parts of the eye. It is particularly important when affection of the anterior eye segment is not very clear.

Many ophthalmologists justly demand a careful approach to the prognosis of the eye burn immediately after the trauma and suggest that its severity be determined only a few days later.

It is obviously expedient to make a diagnosis twice in each case: a preliminary diagnosis on the day of the burn and a final diagnosis seven or eight days later, which will be the principal one.

Besides the classifications specifying the degree of severity and the depth of affection, there are others which determine the stages in the development of the burn process (Zagora, 1961; Kaznelson, 1962; Poltinnikov, 1964, 1965; Tartakovskaya, 1969, and others).

In studying the dynamics of the burn process, Kaznelson (1961, 1962) showed that the functional shifts in the eye are not stable, but are marked by a definite cyclic character. He believes that for a correct understanding of the pathophysiology of changes in eye burns, as well as for planning the therapeutic tactics, it is essential to distinguish four stages in this process, namely:

first stage—immediately after the burn;
second stage—of marked trophic disorders;
third stage—vascularization of the cornea;
fourth stage—cicatrization.

Disturbances of metabolism in the tissues, particularly of vitamin and carbohydrate, and of oxidation processes, depend on the stage of the burn process, the degree of severity of the burn, and supply of nutrients. Treatment of eye burns should be prescribed with due account for these factors (Kaznelson, 1961; Blinova *et al.*, 1961; Kaplunovich, 1964, and others).

Tartakovskaya (1969) described the stages of the burn process most fully. Accepting the division of the eye burn disease given in stages by Kaznelson, she believes it expedient to combine the stage of trophic disturbances and that of vascularization into one single stage, because ac-

tually corneal vascularization accompanies the stage of trophic disturbances and it is difficult to differentiate them.

The first stage, acute postburn stage of the disease, is characterized by copious mucopurulent discharge, swelling and hyperaemia of the conjunctiva of the eyelid and eyeball, lesion of the peripheral looped network of the perilimbal vessels, epithelial desquamation and lesions of the surface layers of the stroma. As a result of these changes, marked swelling and infiltration of the cornea develop.

The second stage, that of pronounced trophic disturbances and subsequent vascularization, is characterized by profound dystrophic disturbances in the cornea and other ocular coats, which is manifested clinically by a sharp diminution of corneal sensitivity, recurrent ulcerous defects in the cornea, deep infiltration of its stroma and symptoms of flaccid chronic iridocyclitis, which, in particularly severe cases, is attended by fibrohaemorrhagic exudation into the anterior chamber. The process may be accompanied by a decrease or rise in intra-ocular pressure. At the same time, there is more or less intensive formation of new vessels and their growth into the cornea.

The third, cicatricial stage, is marked by the formation of new coarse connective tissue, as a result of which stable corneal opacity of various intensity and length occurs.

The burn process in the eye constitutes a complex development of morphological, biochemical and other types of disturbances occurring both due to the effect of the damaging agent and as the result of secondary changes included in the chain of the pathogenesis. From this stems the need for a scrupulous, well-grounded pathogenetic treatment, with due account for the degree of the affection and the stage of the pathological process.

In summing up the above stated, it should be stressed again that to choose the most effective therapy and correctly assess the effectiveness of the therapeutic methods applied, it is necessary to use a single standard classification of eye burns.

CHAPTER IV

# Clinical Peculiarities in the Development of the Burn Process

The large variety of aetiological factors which may lead to an eye burn has been mentioned above. It is very difficult however, to judge the aetiological factor from the clinical picture. Certain peculiarities of damage caused by an acid, alkali or high temperature can be detected only in the very first hours after the accident (Ochapovskaya, 1946; Zagora, 1961, and others).

The pattern of the pathological process is homogeneous in many respects depending primarily on the degree of the initial damage to the ocular tissues. Duke-Elder (1954) notes that in most cases, despite the difference in the mechanism of damage to the ocular tissues under the effect of various harmful agents, the clinical pathology of the developing process is quite similar and depends more on the strength of the damaging factor than on its character. Those changes which are encountered in the clinical course and on examination by pathologists are mainly the consequence of the death of cells and are only remotely associated with the peculiarities of the initial damage. In full agreement is the opinion voiced by Ochapovskaya (1941) that all chemical substances (we may add also thermal factors) have a destructive effect on the ocular tissues, whereas all the diversity of the clinical picture is merely explained by the degree of destruction which depends on a number of factors.

We have analysed the case histories of 642 patients (943 eyes) with fresh burns of various aetiology and degree of severity. Both eyes were affected in practically half of the patients, but the degree of damage was not always the same: severe and very severe burns were combined with mild or moderately severe burns, but in some cases the

damage was of the same type. Table 6 shows the distribution of eye burns according to the cause of the burn and the degree of its severity.

It also shows that heterogenous aetiological factors may cause eye damage of different severity.

*Table 6.*

DISTRIBUTION OF EYE BURNS AMONG THE MAIN AETIOLOGICAL GROUPS ACCORDING TO THE SEVERITY OF THE BURN

| Degree of severity of burn | Number of eyes | Aetiology | | | | |
|---|---|---|---|---|---|---|
| | | Acid | Alkali | Thermal | Thermo-chemical | Other substances |
| Mild | 363 | 43 (34.15%) | 160 (32.6%) | 100 (47.4%) | 22 (35.5%) | 38 (71.7%) |
| Moderate | 189 | 25 (19.8%) | 106 (21.6%) | 39 (18.5%) | 8 (12.6%) | 11 (20.7%) |
| Severe | 223 | 15 (11.9%) | 149 (30.3%) | 42 (19.9%) | 14 (22.6%) | 3 (5.7%) |
| Particularly severe | 168 | 43 (34.15%) | 76 (15.5%) | 30 (14.2%) | 18 (29.0%) | 1 (1.9%) |
| Total: | 943 | 126 (100%) | 491 (100%) | 211 (100%) | 62 (100%) | 53 (100%) |

That is why the assertion of certain ophthalmologists of the predominating severity of this or that burn (alkaline, acid, etc.) is hardly warranted. The severity of the burn depends on the chemical and physical properties of the damaging factors: the amount and concentration of the agent, the temperature, pressure, period of exposure, and so on. Molten metals, depending on the melting point, cause both mild and extremely severe eye burns; particularly severe burns with extremely unfavourable outcomes were also encountered in damage caused by various acids, ammonium and lime. The combination of marked chemical activity of the agent and high temperature is extremely hazardous.

## MILD EYE BURNS

More than a third of the patients (38.4 per cent) treated in the hospital for eye burns had mild lesions.

It should be noted that all the aetiological factors enumerated above could have been the cause of mild burns, moreover the substances not included in the four main groups of damaging agents and referred by us to the 'other' group (aniline dye, acetone, nitrocellulose varnish, iodoform, potassium permanganate, alcohol, oil and others) caused mainly mild burns.

In most cases with mild burns the clinical picture of the eye lesion was the same irrespective of the aetiological factor. It was characterized by hyperaemia and moderate swelling of the skin of the eyelids, signs of irritation of the eye, hyperaemia of the conjunctiva and damage to the corneal epithelium over a large or small area.

Biomicroscopy showed mild swelling in the region of the erosion in the topmost corneal layers, which vanished without a trace with the gradual epithelization of the cornea. Corneal sensitivity was sometimes diminished, but not sharply. The iris and the ciliary body were not involved in the process.

Mild eye burns are usually attended with pronounced subjective sensations: photophobia, cutting pain in the eye and lacrimation. Visual acuity is slightly lowered to a few tenths, but lower levels are possible when the damaged opaque epithelium has not yet been rejected from the underlying cornea, in concomitant pathological conditions not associated with the burn (cataract, myopia, etc.).

Let us dwell on the mild eye burns the clinical picture of which differs from the one described above. In burns by mineral acids or in thermal burns, when exposure to high temperature is fleeting (in the flash of an electric welding arc, etc.), the damaging effect of the burning agent consists in the instantaneous coagulation of the superficial layers of the corneal epithelium. In the first hours such burns may simulate severe eye damage. But if we carefully remove the necrotized epithelium with a moistened cotton tampon, we shall find that the corneal tissue proper is absolutely transparent and the epithelization of the cornea occurs rapidly and without complications. Certain substances stain the ocular tissues (potassium permanganate crystals, aniline dye, and others).

Mild burns may be combined with the penetration of small foreign bodies into the conjunctiva and cornea (in gunpowder and carbide explosions, etc.).

Mild burns follow a favourable course. The inflammatory process in the conjunctiva and epithelization of the cornea are usually completed in four or six days, and the patient recovers with full restoration of visual functions and corneal sensitivity. In rare cases, however, complications may occur also in mild burns. Concomitant secondary infection may lead to the formation of infiltrates in the cornea and an inflammatory reaction in the iris, in which case the process lasts longer.

Quite often a very unfavourable course is encountered in burns by steam. Having begun as a mild lesion, it may take a protracted course with recurrences and end with a considerable loss of vision.

## MODERATE BURNS

In moderate burns (II degree) vesicles form on the skin of the eyelids due to accumulation of exudate between the cornea and Malpighian layer of the epidermis. The skin around the vesicles is hyperaemic and swollen and the eyelids may be so tense that they are opened with difficulty by means of eyelid levators. In an aseptic course of the burn, epithelization of the area of the wound takes place in eight to ten days at the expense of the undamaged peripheral epithelium and the epithelium preserved in the burn area. Infection of the burn wound leads to the formation of loose crusts covering the eyelids completely. Healing in such cases is slower, but as a rule no scars remain on the skin.

The mucous membrane shows signs of chemosis, ischaemia and superficial necrosis (mainly the epithelial layer), as a result of which the conjunctiva appears whitish. In some cases fibrin exudates form on the conjunctival surface which may cause loose adhesion between the eyelid and the eyeball. The strands of fibrin are easily separated with a glass rod. Deep in its fornix the conjunctiva is usually hyperaemic; after the superficial films have been removed with forceps it can be seen that the conjunctiva is vascularized all over. Tartakovskaya (1968) who studied the condition of the perilimbal and ciliary vessels during a burn process noted that in the first 24 hours after a moderate burn the capillary loops dilate and vasomotor paresis of the capillary network occurs. Due to increased permeabi-

lity of the capillary membranes marked swelling of the conjunctiva develops which, in turn, may lead to compression of the capillary loops and the formation of large areas of conjunctival ischaemia.

Functional spasm of vessels of the peripheral looped network may also occur in the limbus, which is quite rapidly replaced by their dilatation and some swelling of the limbal zone (Nazarova, 1963).

Conjunctival damage is attended with moderate mucopurulent discharge, a culture of which does not always produce growth of microbial flora.

The degree of corneal damage is of prime importance for the outcome of the burn. In moderate burns changes predominate in the anterior corneal layers. They are manifested by a more or less pronounced swelling of the corneal tissue and damage to the epithelium. In the first hours after the burn the epithelium can still be seen on the corneal surface, but it is loose, its connection with the underlying stroma is weak; and it is very rapidly rejected and erosions form. Biomicroscopy shows that the swelling prevails in the superficial layers of the cornea.

Examination of the cornea in polarized light (Puchkovskaya, Novokhvatsky, Nepomyashchaya) gives a clearer idea of the character of changes in it, and provides more grounds for differential diagnosis between severe and moderately severe corneal lesions. From the clinical aspect the cornea is dull, opaque, resembling a lustreless glass of medium intensity. It is possible to discern through it the anterior chamber, the pupil and dull-pink reflex from the fundus oculi. Corneal sensitivity in the burnt area is usually drastically diminished or lost.

Burns of moderate severity as a rule involve the iris in the pathological process, in which case serous iritis develops most frequently and disappears in a few days. In rare complicated cases there is concomitant iridocyclitis with exudate into the anterior chamber.

Acuity of vision is greatly impaired in moderate burns due to marked swelling and disturbed optic properties of the cornea. Vision usually ranges from several hundredths to one or two tenths, and is rarely higher.

The patient complains of sharp photophobia, lacrimation and pain in the eye which pass as the inflammatory process gradually subsides.

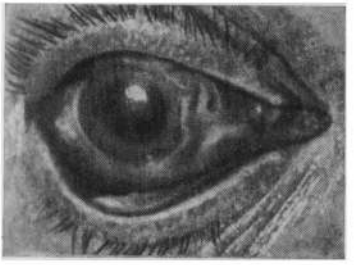

FIG. 10. Lime burn of conjunctiva and cornea, moderate severity.

Burns of moderate severity (Figs. 10, 11) usually occur without complications. While causing relatively mild and in most cases reversible damage to the eye tissues, moderate burns usually do not pass through all the developmental phases characteristic of a pathological process in severe and particularly severe eye burns. Thus, after the first (acute) stage the phase of regeneration takes place quite rapidly. In burns of moderate severity the normal structure of the corneal and conjunctival tissues may be fully restored. As early as on the second or third day, ischaemia of conjunctival areas is replaced by total vascularization and subsequent hyperaemia, the desquamated conjunctival epithelium is restored, and epithelization of the cornea begins. In uncomplicated cases epithelization of the cornea is completed within six or eight days, and is paralleled by diminished swelling of the cornea and increase of its transparency. Regeneration is particularly intensive if undamaged areas of epithelium, small as they may be, are preserved in the cornea; they serve as the source for regeneration. In total corneal erosion, the epithelium proliferates over the cornea from the conjunctiva. This is why, in severe conjunctival burns combined with moderate damage to the cornea, regeneration of the cornea is delayed. It remains swollen for a long time and favourable conditions are provided for intensified cellular infiltration of the cornea and growth of vessels into it. In such cases the process may terminate in the formation of irreparable corneal opacities.

FIG. 11. A II-degree thermochemical burn (in explosion of metallic sodium) of the skin of the eyelids and face; a severe burn of the right eye and moderately severe burn of the left eye.

Karmysheva (1950) who studied the reaction of the cornea to a trauma (a burn, in particular) believes that it is necessary to distinguish reactive and inflammatory processes in it.

**Reactive changes** always accompany damage to the cornea and are manifested by its swelling, thickening and loosening of the corneal laminae and some infiltration with leucocytes. These phenomena intensify for two-three days after which, in uncomplicated cases, the number of leucocytes gradually decreases and corneal swelling diminishes. By the end of the week only occasional leucocytes are detected in the cornea. The reactive changes do not impair regeneration of corneal transparency.

**Inflammatory changes** are distinguished from reactive changes by drastic swelling and loosening of the laminae, and very copious leucocytic, predominantly neutrophil, infiltration. The cornea is cloudy. The development of concomitant inflammation disturbs the process of corneal regeneration; in such cases a stable opacity, leucoma, forms.

More or less pronounced inflammatory changes are inherent in all severe burns. They may also develop in complicated burns of moderate severity. Complications of moderate burns comprise corneal infiltrations, recurrent erosion and exudative iridocyclitis. In severe burns intra-

ocular pressure usually does not rise. It usually remains within normal levels but may become somewhat lower in marked iridocyclitis. With rational therapy the outcomes of most moderate burns are favourable.

Superficial damage to the conjunctiva terminates in complete restoration of its normal structure; in one and a half to two weeks the transparency of the cornea and visual acuity are completely restored.

If the regeneration processes in the cornea are not sufficiently active (which may occur in diminished reactive forces of the organism, concomitant infection, etc.), the pathological process is retarded in its development and conditions are created for the growth of connective-tissue elements in the cornea. In such cases the process terminates in the formation of superficial opacities, and in most unfavourable cases—of vascularized leucomas which considerably impair vision.

## SEVERE BURNS

In severe burns the pathological process is characterized by deeper disturbances in the vital functions of the ocular tissues, while severe complications caused by these disturbances often lead to total loss of visual function and the patient's disability.

Necrotic irreparable changes in the tissues of the eyes are typical. Ophthalmologists sometimes neglect severe affections of the skin of the eyelids. This is to be explained by the fact that many chemicals, while causing the severest burns of the conjunctiva and cornea, have a weak effect on the skin. Even the most active substances (e.g. caustic alkalis, freshly slaked lime, ammonium and others) usually cause burns which are not severer than II degree. Deep lesions of the skin of the eyelids, however, may be encountered in cases with thermal burns and burns caused by concentrated mineral acids, requiring timely assessment and active therapy.

Thies (1938), Polyak (1957), Lebekhov (1958), and Ushakova (1960) described the clinical course and morphological changes in thermal lesions of the eyelids.

Severe burns of the eyelids include extensive III degree affections, the distinguishing feature of which is the formation of a dark scab as the result of coagulation necrosis

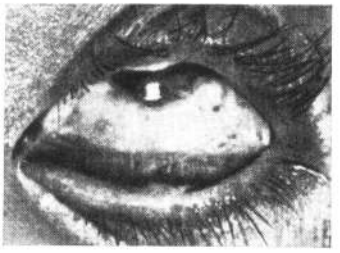

FIG. 12. A severe chemical burn of the conjunctiva and moderately severe burn of the cornea.

of the tissue proteins, drastic dehydration of tissues and disturbances of their vital activity. In severe III degree burns all the layers of the skin are damaged while in IV degree burns the underlying subcellular tissue, the muscle and the cartilage are also involved.

More or less deforming scars always appear after a III degree burn; in contamination of the burn wound and flaccid course of regeneration processes they may be coarser.

Burns of IV degree leave still deeper scars; the necrosis in such burns spreads to all the layers of the eyelid, sometimes even exposing the orbital bones. If the IV degree burn is limited to a small area, it is still considered a severe one. A burn spreading over more than half of the eyelid is considered particularly severe. Even a limited III or IV degree burn is attended with marked swelling and hyperaemia of the surrounding skin, sometimes of all the face.

Involvement of the conjunctiva in severe burns is characterized by extensive ischaemia and areas of deep necrosis, not exceeding half the surface of the eyelids and eyeball. In necrosis the conjunctiva appears as a loose lifeless tissue in which only occasional dark vessels are seen; the process usually spreads to the episcleral layers (Figs. 12-14).

In biomicroscopy of severe burns ectasia, stenosis and occlusion of the conjunctival vascular lamina with thrombi are seen. More or less coarse organic changes of the vessels of the peripheral looped network, with their thrombosis

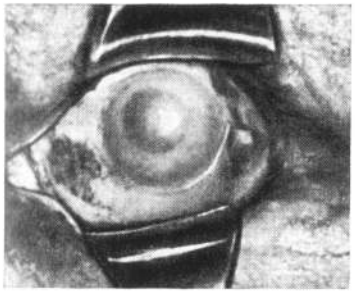

FIG. 13. A severe lime burn of the conjunctiva and cornea.

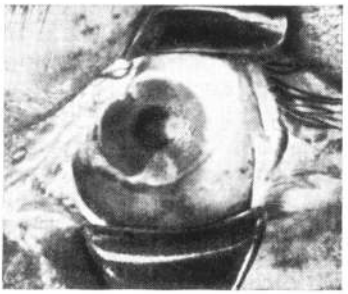

FIG. 14. A severe burn of the eye with sulphuric acid.

or even total destruction, can be found when the region of the limbus is damaged. The limbus appears as a wide white band with 'shreds' of the remaining vessels. The degree of damage to the vessels may differ with the area of the limbus—from zones of total anaemization or considerable injury to vessels, to zones where the vascular changes are purely functional and displayed in an angiospasm of a reflex or tōxic nature.

Much significance is attached to damage to the conjunctival vessels, particularly of the peripheral looped network in the development of the pathological process in severe and particularly severe eye burns; intensification of corneal opacities (the so-called 'secondary opacity'), iridocyclitis, secondary glaucoma, etc. are associated with them.

It is not always possible to differentiate, however, between a functional angiospasm and irreversible organic changes in the vessels from the clinical picture and even from biomicroscopic examination. The acetylcholine test, which we widely apply in clinical conditions, is of much assistance in studying the condition of the vessels. Frequent instillation of an active vasodilating drug (which is not necessarily acetylcholine), or its injection under the conjunctiva, results in dilatation of vessels which are in a state of functional spasm with no effect on destroyed vessels. The conjunctiva turns pinker, particularly in areas least damaged; biomicroscopy reveals restoration of blood flow in these zones. Bleeding occurring after Passov-

Polyak's peritomy, or simply after an attempt to remove the necrotic films with forceps, also indicates that part of the vessels have been preserved, which is a favourable prognostic symptom in severe burns.

There is usually no swelling in the zone of a severe burn of the conjunctiva, because it is loose and fluids easily pass through it. Disturbances developing in the walls of the vessels promote exudation of blood from the conjunctival capillary network and formation of extensive subconjunctival haemorrhages.

Severe damage to the cornea is characterized by marked destructive changes in all its layers. Irrespective of the cause of the burn, disturbances are seen not only in the epithelium and stroma, but also in the endothelium in the hours immediately after it.

Depending on the area of spread, III and IV degree corneal burns may be regarded as severe (see classification). In III degree burns the whole cornea seems cloudy, the opacities occupy all its layers. The cornea resembles an intensively opaque plate through which it is possible to discern the outlines of the pupil; elements of the anterior chamber and reflex from the fundus, however, are not defined. Such a corneal burn differs in the clinical picture from moderate burns in which the corneal opacities still resemble opaque glass, though less intensively, and are mainly found in the anterior layers and depend mostly on the diffuse swelling of the cornea. In burns of moderate severity, the colour of the iris can be distinguished and a dim reflex can be detected from the fundus.

In IV degree burn, due to total destruction of all the elements of the cornea, the opacities are so intensive, that the cornea looks like a porcelain plate as Grant (1952), Pavlyuchenko (1956) and Polyak (1957) aptly describe it.

Corneal damage of the IV degree may be regarded as a severe burn only if it occupies not more than half of the corneal surface. It is very important to bear this in mind in prognosticating the outcomes of a pathological process in severe eye burns. Maintenance of certain transparency of the deep layers in severe III degree burns of the cornea or slightly damaged corneal areas in deeper but limited burns of IV degree gives grounds to presume that in severe burns a certain part of the corneal tissue elements remains viable or is in a state of profound inhibition of vital fun-

ction (parabiosis). In favourable conditions the vital activity of these tissues may be normalized and, consequently, visual functions more or less restored. In total IV degree damage to the cornea its normal structure is past restoring, since the processes of reparation here develop as replacement of the necrotic tissue by connective-tissue elements. The outcomes of severe and particularly severe eye burns are therefore different too.

Profound damage to the cornea results in rapid death of nerve endings found mainly in the anterior layers, so photophobia and signs of irritation are less pronounced in the first days after severe and particularly severe corneal burns than after moderate and mild burns. Corneal sensitivity is always absent in the zone of a severe burn.

In severe burns visual acuity is usually sharply reduced due to intensive corneal opacity; in most cases it varies within the limits of $\frac{1}{\infty}$ pr. certa—0.02-0.03. Exceptions to the rule are burns by some alkalis (by ammonium, for instance), in which the opacity of the cornea is initially not pronounced despite the severe damage to all parts of the eye and visual acuity of the patient on admission may even be 0.2-0.3.

Besides lesions of the tissues of the anterior eye segment the development of early concomitant symptoms like increased intra-ocular pressure and marked iridocyclitis is characteristic of severe burns. An inflammatory process in the iris, and often in the ciliary body, always accompanies severe eye burns irrespective of the aetiological factor which had caused the burn.

The cardinal symptoms of inflammation of the iris, namely, hyperaemia, its blurred pattern and change in colour are rarely visualized in a severe burn, because the intensively opacified cornea prevents discerning the parts of the anterior chamber. That is why we judge the degree of inflammation of the iris, and its rigidity due to blood congestion, by the condition of the pupil, its reaction to mydriatics. An important aid in diagnosing iridocyclitis in a severe burn is biomicroscopy in infrared rays which not only allows us to observe changes in the size and shape of the pupil (posterior synechia) but also demonstrates the presence of exudate in the anterior chamber when the cornea is not transparent.

In severe eye burns iridocyclitis is often of a plastic type with exudation into the anterior chamber and formation of posterior synechia along the pupillary edge. When areas of more or less transparent cornea are preserved, or when it clears up on treatment, grey precipitates on its posterior surface may be seen.

We encountered marked exudative iridocyclitis on 34 eyes (15.2 per cent) out of the 223 cases with severe eye burns, the exudate appearing in the anterior chamber of 18 eyes early within the first three to eight days, and in 16 cases much later, after the second week. In 8 patients the exudate was haemorrhagic. The frequent occurrence of iridocyclitis is explained by profound changes developing in eye burns of any aetiology not only in the vessels of the conjunctiva, episclera and peripheral looped network, but also in the ciliary body and even in the vascular membrane of the eye proper far beyond the limits of the burn area (Poltinnikov, 1965, and others).

Impaired regulation of intra-ocular pressure often occurring in severe and particularly severe eye burns is associated with changes in the uveal tract.

Numerous clinical observations show that iridocyclitis in severe burns is only rarely attended by marked hypotony of the eye. Tendency to increased intra-ocular pressure is noted far more often, which considerably aggravates the course of the burn and testifies to the involvement in the burn process of the deep parts of the eye.

Severe and particularly severe eye burns are an unfavourable combination of affection of the cornea and the vascular network of the eye (vessels of the conjunctiva, episclera and choroid). Each of these factors may lead to a rise in intra-ocular pressure.

According to various authors, increase in intra-ocular pressure is encountered in 8 to 50 per cent of cases with eye burns (Parkhomenko, 1962; Kovalev, 1962; Votockova, 1962; Isaeva, 1964; Kaplunovich, 1964, 1968; Lazarenko, 1965; Heydenreich, 1966; Tartakovskaya, 1968, and others).

There are two commonly recognized forms of a rise in intra-ocular pressure: in the first days after the burn (up to ten days) known as **reactive hypertension**, which is comparatively easily controlled by treatment, and a rise of intra-ocular pressure at a later period, a few weeks after

the burn when true **secondary glaucoma** develops, which is poorly responsive to common methods of therapy.

This differentiation is connected with various genesis of the disturbance of intra-ocular pressure at different stages in the development of the burn process.

In experimental alkaline burns intra-ocular pressure considerably increases (up to 59 mm Hg) in the first fifteen seconds and then gradually decreases within one hour (Stein *et al.*, 1973; Paterson and Pfister, 1974, and others). The authors connect the rise in intra-ocular pressure with thickening of the ocular tissues due to the effect of alkali, since it is also encountered in isolated eyes where there is no influence of such factors as disturbed circulation, muscular spasm, pain and others.

It is difficult to mark the peak of the initial rise in intra-ocular pressure in patients since it is transient. A considerable rise in intra-ocular pressure may be registered in the clinic, however, on admission of patients with severe eye burns soon after the trauma had occurred.

In the first hours and days after the burn the rise in intra-ocular pressure is directly linked with the trauma itself, first and foremost with damage to the aqueous veins and impaired permeability of the haemato-ophthalmic barrier (Votockova, 1962; Kaplunovich, 1969). A considerable role is also attributed to marked hyperaemia and paralysis of vessels of the ciliary body with rapid exudation into the aqueous humour, and the formation of hypopyon or hyphaemia (Ochapovskaya, 1946; Heydenreich, 1966).

Tartakovskaya (1968) contends that reactive hypertension is connected with change in the secretion of aqueous humour caused by neurovascular disorders resulting from the burn.

The development of secondary glaucoma is to a large degree connected with anatomical changes arising in the development of the inflammatory process and hampering metabolism of intra-ocular fluid. These include growth of connective tissue in the angle of the anterior chamber and hyper-regeneration of the endothelium, obliteration of the angle, exudate in the anterior chamber, anterior and posterior synechiae, thrombosis and stasis in the uveal tract, increased vascular permeability leading to intensified transsudation into the ocular cavity (Voino-Yasenet-

sky, 1965; Heydenreich, 1966; Kaplunovich, 1968; Voino-Yasenetsky and Klyutsevaya, 1970, and others).

The division of disturbances in intra-ocular pressure in eye burns mentioned above is very conditional, because even in the description of their mechanism it is already seen that the same factors may be of importance both in early and later instances of the development of hypertension, such as the exudation into the anterior chamber, lesion of the uveal tract, impaired drainage due to spasm and subsequent obliteration of the draining vessels, etc.

We failed to define an interdependence of the aetiology of the burn and the frequency of secondary glaucoma. In all types of burns some of the patients had disturbances in intra-ocular pressure.

Clinical observations showed that just as other clinical symptoms the frequency and character of increased intra-ocular pressure are primarily determined by the severity of damage to the eye.

We observed increased intra-ocular pressure in 48 eyes out of 223 (21.5 per cent) with severe burns, in 19 eyes at early stages (on the first to eighth day), and in 29 eyes at later periods (from 12 to 40 days).

In a severe burn the pathological process goes through all the stages of the burn disease: the acute, a stage marked by pronounced trophic disturbances and vascularization, and that of cicatrization. The correlation of these stages varies, depending on the severity of the burn, the treatment applied, the time of admission to the hospital, the state of the organism's reactivity, etc. The outcomes of severe burns vary to a great extent depending on these same factors.

Even in relatively favourable cases, in the first few days after a severe burn there are often intensified opacities of the cornea due to its swelling and cellular infiltration, expansion of necrotic zones of the conjunctiva, and an increase of inflammation in the uveal tract. If relatively small areas of the conjunctiva are involved in the necrotic changes, their revascularization from the surrounding tissue is possible with the formation of small scars which are hardly noticeable and cause no deformities of the conjunctival fornices. In a more extensive and deeper necrosis of the conjunctiva spreading also to the scleral layers, the necrotic conjunctiva is rejected from the underlying

sclera and its defect is gradually filled with granulation tissue. The severer the sclera is burnt, the slower the granulation of the necrotic area is. The necrotized conjunctiva may be replaced by fibrous elements, without being rejected, by means of the gradual resorption of the dead cells with inflammatory infiltration of the damaged area. At the same time rich granulation tissue also grows, which gradually shrinks and forms scars distorting the conjunctival fornices and impeding the normal movements of the eyeball. The degree of cicatricial changes of the fornices depends on the area and depth of the conjunctival affection.

Damage to the conjunctiva to a large degree influences the regeneration of the cornea. Severe burns of the cornea, attended with moderate burns of the conjunctiva, often occur without complications with rapidly developing epithelization, considerable resorption of corneal opacities and relatively poor vascularization. Severe necrosis of the conjunctiva impairs corneal nutrition, intensifies intoxication and provides better conditions for the development of infection and various complications in the course of the burn.

A special role in the development of pathological changes in the cornea belongs to the extent of damage to the peripheral looped network, which becomes the mainstay in supplying the cornea with nutrients when the borderline membranes are destroyed (Duke-Elder, 1954; Pavlyuchenko, 1958; Polyak, 1961, 1965; Kaplunovich, 1968; Tartakovskaya, 1968; Brown *et al.*, 1969, and others).

Clinical observations show that the cornea suffers most in the segment where the perilimbal vascular network has been completely destroyed. Corneal ulcers and infiltrates develop here most frequently and partial perforations of the cornea at the limbus may occur.

## PARTICULARLY SEVERE BURNS

The fourth group of burns, which Polyak terms 'particularly severe' and Thies 'catastrophic', comprises the gravest, often irreversible eye injuries, the prognosis of which is almost invariably unfavourable. Among them are mainly IV degree burns for which the same features of ocular-tissue necrosis, as those described above in severe

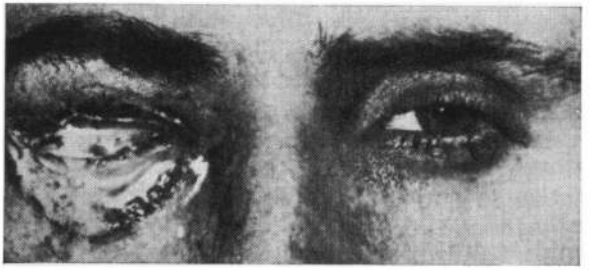

FIG. 15. A particularly severe thermal burn of the eyelids and of the eyeball.

burns, are typical, and even more pronounced and widespread. IV degree burns of the skin of the eyelids are very rare and may occur due to either very high temperatures (e.g. with molten metal of a high melting point), or concentrated mineral acids (most often sulphuric acid). If IV degree burns involve a large area of the eyelids, they are particularly hazardous, because they, first, are often combined with equally severe affections of the eye and aggravate a grave pathological process in the eye; and second, because wounds on the eyelids and rejection of necrotized edges of the eyelids hamper therapeutic procedures and surgical manipulations. If the eyeball has not suffered such a severe burn, subsequent cicatrization of the skin of the eyelids, resulting in ectropion and lagophthalmos, may become complicated by keratitis due to incomplete closure of the palpebral fissure. In injury to the edges of the eyelids their partial or total adhesion to each other (ankyloblepharon) may occur (Fig. 15).

Burns in which necrosis spreads over the greater part of the eyeball and may involve the conjunctiva on its posterior surface also take a particularly severe course. The conjunctiva turns into a greyish-white scab with a dull, often wrinkled surface and becomes dry and brittle; thrombosed vessels are seen as dark bands in the region of the fornices and there are haemorrhages under the conjunctiva.

When the sclera is involved in the burn process, the overlying conjunctiva around the limbus is quite rapidly rejected; if thinning of the cornea also occurs the eye may resemble a porcelain prosthesis (Fig. 16).

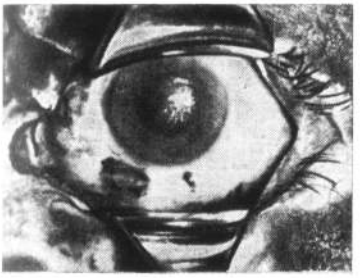

FIG. 16. A particularly severe burn of the conjunctiva and cornea with concentrated sulphuric acid.

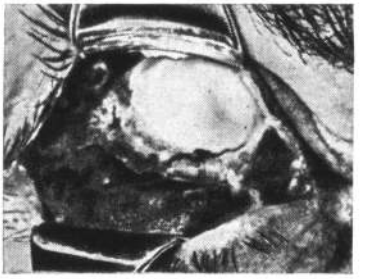

FIG. 17. A particularly severe lime burn of the conjunctiva and cornea.

In a particularly severe burn the whole cornea or most of it undergoes necrosis which spreads to all its layers. The cornea resembles a porcelain or greyish-white plate, through which even the contours of the pupil can usually not be discerned (Fig. 17). There is a complete loss of corneal sensitivity, its surface is dry and opaque. Following rejection of the epithelium the whole cornea is stained with fluorescein.

Primary and secondary corneal opacification are distinguished (Ochapovskaya, 1947; Tartakovskaya, 1969, and others).

Primary opacification of the cornea is directly associated with effect of the damaging agent on the tissue. In acid and certain thermal burns the cornea usually appears more opaque immediately after the trauma than in alkali burns of the same severity. It looks like 'the eye of a boiled fish' or a boiled egg-white, but in two or three days the cornea clears up a little, which may be mistaken by an inexperienced physician as a sign of improvement. In fact the corneal layers, which have been in a direct contact with the burning agent, coagulate immediately and, lacking any vital bond with the less affected deeper layers, are rejected from them. The cornea thins out to a degree depending on the depth of its damage. At times, after rejection of necrotic layers, only the transparent Descemet's membrane most resistant to damage remains.

If corneal damage was not very deep, then, after the rejection of its anterior layers, it appears not very cloudy

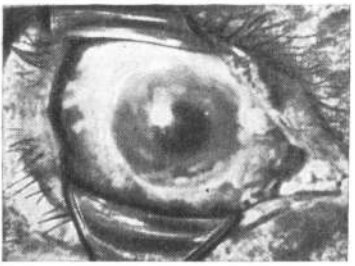

FIG. 18. A particularly severe burn of the conjunctiva and cornea with concentrated sulphuric acid.

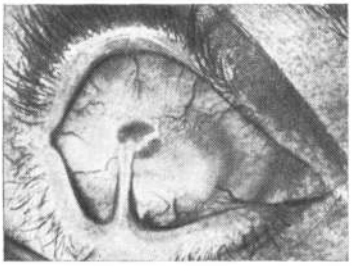

FIG. 19. The outcome of a particularly severe eye burn with concentrated sulphuric acid.

at first; parts of the anterior chamber, the pupil and the lens can be seen (Fig. 18). Gradually, however, secondary opacity of the cornea sets in due to trophic disorders and toxic processes in the cornea, and a coarse vascular leucoma forms (Fig. 19).

In particularly severe alkaline burns tissue destruction is slower, but the deeper corneal layers are immediately damaged. In view of the fact that in alkaline burns death of the cornea follows the pattern of moist necrosis, corneal opacity may not seem so intensively 'porcelain' as in acid or thermal burns. The cornea has a greyish hue and is also completely non-transparent (with the exception of certain types of alkaline burns). The necrotized anterior layers are rejected later than in acid burns, in seven-ten days. When the cornea thins out, the deep layers do not appear fully transparent, although this process is likewise attended with certain 'clearing up' of the cornea. Later, if corneal perforation is avoided, a coarse vascular leucoma develops with proliferation of cicatricial tissue over the cornea. The cornea is repaired at the expense of massive cellular infiltration and replacement of its tissue by fibrous elements, the process being attended with copious vascular growth, which, in this case, is a positive factor promoting more rapid regeneration, because vascularization strengthens the cornea and prevents its perforation.

Even in the favourable course of particularly severe burns, visual functions are considerably impaired and visual acuity does not exceed several hundredths.

In particularly severe burns deep trophic disturbances, marked toxic reactions and long delays of regeneration processes often bring about serious complications—ulcers and infiltrates of the cornea. In the severest cases, when the corneal burn is attended by the severest damage to the conjunctiva and its rejection from around the limbus, reparation processes take long to develop. This leads to the perforation of the cornea and the prolapse of the iris, and even of the lens, if perforation is extensive. The process terminates with the subatrophy of the eyeball or the formation of a coarse cicatricial leucoma, adhering to the iris, secondary glaucoma, a sharp reduction in the visual function to light perception with incorrect light projection, even to zero.

Concomitant infection, which finds good soil to thrive on in particularly severe burns, may aggravate the burn process and in some instances also be the cause of complications.

Iridocyclitis and secondary glaucoma, which are frequent concomitant symptoms of eye lesions, follow a graver course in these cases than in severe burns.

We encountered severe iridocyclitis in all cases of particularly severe burns; in 58 out of 168 eyes (34.5 per cent) it was attended either with exudation or haemorrhages into the anterior chamber. Even more frequently, in 41.4 per cent of all cases (70 eyes), a rise in intra-ocular pressure was observed.

Both iridocyclitis and secondary glaucoma resisted treatment. Recurrent outbreaks of inflammatory phenomena and episodes of drastic rise in intra-ocular pressure were observed. It is characteristic that in most cases of particularly severe burns a rise in intra-ocular pressure and exudation into the anterior chamber were apparent from the very first days after the injury. This confirmed the greatest severity of damage in this group of burns.

Lens opacity, which we observed in 17 cases (10.1 per cent), was a frequent symptom attending particularly severe eye burns. It is very possible that this complication occurred more frequently, but opacification of the lens may usually be distinguished only when the cornea is thinned out or when it has maintained some of its transparency (e.g. in ammonium burn).

We found a cataract in alkaline and acid burns (in seven

and nine eyes, respectively) and even in one eye after a thermal burn (molten aluminium). Practically in all cases opacification of the lens was noted no later than the fifth or eighth day after the burn, which provides grounds for linking it directly with the burn trauma leading to the damage of all parts of the eye, including its deep-lying parts.

It is thus apparent that burns of any aetiology may cause the severest lesions of the eyes with such serious attending symptoms as severe exudative iridocyclitis, secondary glaucoma and lens opacification.

Irrespective of the aetiology, particularly severe burns bring about the most unfavourable outcomes of the pathological process—the formation of coarse vascularized leucomas which are frequently fused with the iris, various degree of adhesions between the eyelids and the eyeball, even to complete closure of the conjunctival sac, marked deformity of the eyelids and their cicatricial ectropion, and partial or total ankyloblepharon.

In describing burns of various degree of severity we laid no stress on the distinctions of the elements of one aetiological group from another, because numerous observations show that such burns may differ from each other in the character of the morphological changes in the tissues only in the first period. The nature and severity of the initial damage are mainly linked with the physical and chemical properties of the damaging agent, which are precisely the factors determining the degree and reversibility of the damage inflicted.

Destruction of the ocular tissues leads to certain metabolic disturbances (of which changes in carbohydrate metabolism in the cornea, disorders of oxidative processes, protein metabolism and vitamin equilibrium have been studied most thoroughly) and also to immunobiological reorganization of the organism.

These disturbances arising independently of the aetiology determine further development of the pathological process after the burn and the level and character of the regeneration of the damaged tissues.

We were able to reveal certain general disturbances in patients with eye burns, besides damage to their organ of vision. The burn trauma was often attended with marked inhibition or excitation of the patient's mental state,

restless behaviour, headache, insomnia and loss of appetite. In some cases there were vasomotor disturbances manifested by vascular hypotonia or increased arterial pressure.

The patiens also had changes in the haemogram: increased ESR, marked leucocytosis with increased number of segmento nuclear leucocytes, relative lymphopaenia and monocytosis.

Mild irritation of the kidneys also developed in burns due to intoxication; protein (from traces to 0.033 per cent and higher) was found in the urine in the absence of a pathological precipitate.

The clinical data cited testify to the fact that a burn trauma of the eyes causes a number of general reactions of the organism, which are the more marked the severer the burn is.

In determining the severity of a burn it is necessary to take into account the time of admission to the hospital. It is far from always that we can judge with assurance the degree of the burn and forecast its outcome immediately after the accident. At times, in burns by certain acids, for instance, an eye affection which seems severe at first glance may take quite a favourable course and, just in a few days, such a burn may be referred to the group of less severe damage than was estimated at first.

The development of the burn process in the eye is considerably more frequently characterized by a mounting degree of severity, particularly in the immediate post-trauma period. That is why it should be emphasized again that in severe eye burns it is necessary to make both a preliminary (on the day of the injury) and a final diagnosis (in seven-eight days) taking into account the early attending symptoms which may be manifest in that period and can add to our opinion on the depth and severity of the burn trauma and also on the individual peculiarities in the development of the pathological process.

CHAPTER V

# The Principal Methods of Drug Treatment of Eye Burns

The main purpose of the diverse and numerous research into the pathogenesis of eye burns lies in the elaboration of efficacious therapeutic measures which take into account all the complexity of the pathological process, its stages and possible complications.

Very many methods for treating eye burns have been proposed, but most of them are directed at only one of the aspects of the burn process or are based on the empiric use of this or that therapeutic measure. Although various types of eye burns call for somewhat different management, the common character of the pathogenetic process in eye burns of various aetiology enables one to speak of the basic principles of prescribing treatment.

The existing methods of treatment may be differentiated according to their purpose into the following main groups: (1) first aid (removal or neutralization of the damaging agent); (2) antibacterial therapy (prevention of infection); (3) stimulation of metabolic processes and regeneration in the damaged ocular tissues; (4) anti-inflammatory therapy (suppression of the inflammatory process); (5) removal of toxic products accumulated in the tissue as a result of necrotic disintegration; (6) immune therapy (causing an effect on the processes of autosensitization and auto-intoxication); (7) control of remote complications of the burn (recurrent inflammation).

Each of the groups of therapeutic measures listed above has in its arsenal more or less efficacious methods for controlling the severe process developing due to burns of various aetiology.

Nevertheless, the character of the pathological process in burns is so complicated and the mechanisms of patholo-

gical reactions so diverse, that the therapeutic measures applied often prove ineffective, particularly if the burn is very severe or the organism's reactivity is heightened. For that reason treatment should be planned individually for each patient and constantly corrected, depending on the phenomena prevailing at the given moment.

## FIRST AID (REMOVAL OR NEUTRALIZATION OF THE DAMAGING AGENT)

In eye burns there should first and foremost exist a possibility to remove the influence of the harmful agent as quickly and as fully as possible. In chemical burns the 'theoretical ideal' method would consist in the ability to neutralize the chemical substance even before it causes irreparable damage to the tissues. Very few inactivating agents, however, are as yet known which are harmless to the eye, but at the same time able to penetrate the ocular tissues easily.

Among the specific antidotes capable of binding the active radical of the damaging substance are BAL (2.3-dimercaptopropanol, British anti-lewisite) applied in affection of the eyes by arsenic poisons (Uhde, 1946, and others), cocaine in iodine burns (Novotny, 1961), EDTA (ethylenediaminetetra-acetate) or sodium EDTA in lime burns (Grant, 1952; Honegger, 1959; Gundorova *et al.*, 1965, and others). Krejci and Jansa (1968) use diethylenetriamine (DETA) in eye burns by phenol, aldehyde and acids.

Johnstone *et al.* (1973) contend that $Na_2$ EDTA is a specific agent for treating corneal damages caused by concentrated solutions of zinc chloride, silver compounds and certain other substances.

As far back as 1855 Graefe proposed irrigating alkali-burnt eyes with weak acid solutions (Berezinskaya, 1940), while Guilleri (1902) believed it expedient to neutralize acid burns with weak alkaline solutions. These opinions are seconded by some authors in our time too (Ushakov *et al.*, 1965, and others). A phosphate-buffer solution was proposed by some authors as a universal neutralizer in burns by acids and alkalis. On the whole, the trend connected with the search for highly efficacious neutralizers in chemical eye burns should be considered worthwhile. In the opinion of many authors (Wagenmann, 1924; Hug-

hes, 1946; Berezinskaya, 1947; Averbakh, 1949; Duke-Elder, 1954; Polyak, 1957; Shereshevskaya, 1959; Zagora, 1961), however, the principal means of first aid in most chemical burns is immediate and copious irrigation with water or physiological saline, which fulfilling a mechanical role, is usually far more effective since no time is wasted in looking for a neutralizer.

As in no other accidental eye injury, the speed in rendering first aid in chemical burns plays an important role in the further development of the pathological process. For that reason it is so necessary to popularize elementary medical knowledge pertaining to the protection of the eyes, self-aid and mutual aid at production enterprises where eyeburn accidents are possible. It is also important to install special hydrants at enterprises for irrigating the eye with water whenever an accident occurs (McLaughlin, 1946; Shereshevskaya, 1959, and others).

The speed in rendering first aid should be paralleled by its thoroughness. Very often, however, sharply pronounced blepharospasm, pain in the eye, rapid swelling of the eyelids, as well as the fear experienced by the victim of the accident, hinder the thorough irrigation of the conjunctival cavity. That is why immediately after the eye has been irrigated on the spot medical aid should comprise anaesthesia of the eye with a 0.5 per cent tetracaine solution (if the eyelids are very swollen and blepharospasm is marked, akinesia with a 1 per cent procaine hydrochloride solution should also be applied), abundant irrigation of the eye while the eyelids are drawn apart with eyelid-levators, examination of all the conjunctival folds and removal of deeply embedded particles (lime, cement, carbide) with a moist cotton tampon.

## ANTIBACTERIAL THERAPY (PREVENTION OF THE DEVELOPMENT OF INFECTION)

Protection of the damaged tissues from infection is very important in eye burns, because the necrotic tissues are always an excellent substrate for pathogenic flora.

Our clinical and experimental investigations (Nepomyashchaya, Pikhtar) have shown that in nearly 50 per cent of cases microbial flora can be found in the conjunctival

sac of a healthy eye, which, as a rule, is non-pathogenic or conditionally pathogenic.

Pathogenic types of microflora appear in the conjunctival cavity of a burnt eye (haemolytic staphylococcus, *St. aureus*, *Pseudomonas pyocyanea*, etc.) while certain strains of conditionally pathogenic types of micro-organisms acquire haemolytic and plasmocoagulative properties.

The possibility of contamination of the burnt eyes by pathogenic strains of micro-organisms makes it necessary to prescribe antibacterial therapy in all cases of eye burns.

Solutions and ointments of sodium sulphacyl are the most widely used antimicrobial agents (Goldenberg, 1944; Polyak, 1957; Masunova, 1958, and others).

Various antibiotics are widely used in drops and intramuscular injections.

Safarli (1955) employs a phytoncide-naphthalane emulsion. Kanbai (1958) points out the anti-inflammatory effect of naphthalane.

Magalnik (1958) and Kuzina (1958) recommend frequent instillations of potassium permanganate. Noting that in burns the flora of the conjunctival sac is often insensitive to antibiotics, Goryainov (1965) uses imanine (antibacterial preparation obtained from hypericum perforatum), which has an advantage over other antibacterial drugs.

Microbiological studies which we conducted on 78 patients with burns of 124 eyes show that antibacterial therapy does not always provide sterility of the conjunctival sac of the burnt eye. Sterility was achieved in less than one third of the patients (in 37 out of 124 eyes) with eye burns of various aetiology. In many cases growths of non-pathogenic and conditionally pathogenic microbes (68 eyes) and pathogenic microbes (19 eyes) were produced.

Comparison of the presence of microflora with the course and outcomes of the pathological process shows that such complications as corneal infiltrates, exudate into the anterior chamber (hypopyon) and fusion of the cornea develop even when the conjunctival cavity is sterile.

An example of a most severe course of a burn of both eyes may be cited, which terminated in fusion of the cornea when the cultures proved sterile. On the other hand, there are cases when the presence of pathogenic flora has no effect on the course of a burn.

At the same time it is evident that with an increase in

the severity of eye damage micro-organisms are found more frequently in the conjunctival cavity, and the microbial factor is activated, which is obviously connected both with a favourable base for the development of micro-organisms (tissue necrosis) and with a disturbed natural resistance of the organism to infection after a burn.

K., a male, was hospitalized at his local clinic for a thermochemical burn of both eyes. Visual acuity of the right eye was 0.7, and of the left 0.3. The condition deteriorated progressively, deep ulcers and infiltration of the cornea developed. The patient was sent to the Filatov Institute of Eye Diseases and Tissue Therapy. Culture of material collected from the conjunctival cavities of both eyes produced growth of *Pseudomonas pyocyanea* which proved sensitive to neomycin and mycerine. After treatment with neomycin in combination with injections of burn convalescent serum, the condition of the eyes improved greatly, inflammation was eliminated.

The example given shows that the role of the microbial factor in the development of complications in eye burns cannot be completely ignored. In some cases concomitant infection with microbes in a relatively mild burn greatly aggravated the condition of the eyes.

In connection with the wide application of antibiotics in recent years, mainly of penicillin and streptomycin, the number of antibiotic-resistant forms of micro-organisms, cultured from the conjunctival cavity, has considerably increased. According to our observations, *Staphylococcus albus* proved insensitive to penicillin in 88 per cent of cases and to streptomycin in 64 per cent; *Staphylococcus aureus* and *Pseudomonas pyocyanea* were insensitive to penicillin and streptomycin in all cases (100 per cent); streptococcus showed resistance to penicillin in 100 per cent of cases, but was highly sensitive to streptomycin, monomycin, neomycin and tetracycline. Most microbial forms have high sensitivity to monomycin and neomycin, i.e. antibiotics which have become widely used rather recently.

The data cited above indicate that the prescription of antibiotics in eye burns, should, as a rule, be based on a test for the sensitivity to antibiotics of the microflora cultured from the conjunctival sac (for a purposeful suppressing effect on its growth). We (Nepomyashchaya, 1973, and others) found that subconjunctival injections of antistaphylococcal plasma had good results in treating infectious complications of eye burns.

## STIMULATION OF METABOLIC PROCESSES AND REGENERATION IN DAMAGED OCULAR TISSUES

Many non-surgical methods of treatment have been proposed for restoring normal vital activity and metabolic processes in the tissues, the purpose of which is to complement nutrients and other products of tissue metabolism, the lack of which is sharply apparent in burns. Bursuk and Schultz (1940) contend that the Ringer-Locke solution approximates blood serum in the composition of its nutrients, and recommend it for treating eye burns. Pavlyuchenko (1958) and Isaeva (1960, 1964) and other authors include local and intravenous administration of glucose in the complex of burn treatment.

Much importance is attached to the saturation of the organism and eye tissues with vitamins. Frequent instillations of cod liver oil, Hippophae oil, and sperum oil, and introduction of ascorbic acid, vitamins of the B complex, etc. are recommended for the purpose (Tikhova, 1940; Gurevich, 1956; Shereshevskaya, 1959; Nikulina and Kalinichenko, 1971).

Kruger (1959), Němec (1966), and others noted the beneficial effect of ascorbic acid in alkaline burns.

Belavia (1957) speaks of good results in treating eye burns with vitamin $B_{12}$ injections.

Dembo (1963) and Lebekhov (1964) recommend a biological ointment made of retroplacental blood and containing vitamins of the B complex and sodium sulphacyl. They claim that the ointment promotes regeneration of the damaged tissues.

Kaznelson and Saushkina (1950), Kaznelson (1961, 1962), Blinova *et al.* (1961), and Kaplunovich (1964) emphasized the therapeutic importance of vitamins. On the grounds of Kaznelson's assumption on the stadial development of the burn process these authors elaborated a schedule of the combined treatment of eye burns at various stages of the pathological process.

Bearing in mind the sharp inhibition of corneal respiratory functions in burns, Svoboda (1952), Parkhomovsky (1958), Kaznelson (1962), Kaplunovich (1969), and others recommend injecting oxygen under the conjunctiva.

Ilchenko (1964) observed an extremely severe iridocyclitis during oxygen therapy and considers it to be unfavourable.

It is quite possible that the treatment with oxygen injections itself is harmless to the patient, but it may evidently have only restricted use because in tissue necrosis the needed amount of oxygen cannot be injected under the conjunctiva to make a 'cushion' as recommended by this method.

To stimulate oxidizing processes Kuhn (1948) and Cruthirds (1950) used hydrosulphasol, which possesses sulphhydril groups.

Harley (1953), however, did not confirm the value of this method in experiment.

To improve metabolic processes in eye burns, much importance is attached not only to making up for the deficit of nutrients (by means of injections under the conjunctiva, into the vein, and by instillations), but also to restoring the routes by which these substances are delivered to the damaged tissues and, above all, to restoring the peripheral looped network of perilimbal vessels.

To eliminate vascular spasms which occur in the first hours and days after a burn, acetylcholine, tolazoline (Priscoline), rhenicol, Vasculat, Neopevitan, Lambral, Carbachol, Dionin are administered in increasing concentrations, and heat, regular massage of the conjunctiva, etc. are applied (Zwahlen, 1947; Haselman, 1950; Nagy, 1951; Klima, 1952; Langschmidt, 1952; Pur, 1952; Saman and Kozina, 1952; Vilenkina and Fradkin, 1955; Barg, 1956; Uglova, 1959, 1964; Protopopov and others, 1960; Gässler, 1965; Skrzypczak and Jedrosz, 1967, and others).

The purpose of this therapy is to restore the tissue nutrition, dilate the vessels, improve blood and lymph circulation, increase the supply of nutrients and provide for the removal of disintegration products.

Besides its vasodilative effect, acetylcholine has a direct effect on the cornea. Vilenkina and Fradkin (1955) noted that the swelling of the epithelium, even in the form of vesicles, rapidly disappears when a freshly prepared 2.5 per cent acetylcholine solution is applied. It has a trophic influence on the cornea, participating in the transmission of nerve stimulation from neuron to neuron. Uglova (1964) is of the opinion that acetylcholine, before all else, prevents the formation of thrombi in small vessels, intensifying the circulation in them. She recommends treating eye burns with injections of autologous blood and acetyl-

choline, and penicillin, and with separation of the conjunctiva by Passow's method. According to Saman and Kozina (1952), the instillation of Priscol and acetylcholine into the conjunctival cavity not only has a vasodilative effect, but dissolves and washes out harmful toxic substances.

Pur (1952), Duke-Elder (1954), Polyak and Preobrazhensky (1962) have a less optimistic view than other authors on the effect of vasodilative agents, considering them to be beneficial only in treating II degree burns. If the conjunctival and perilimbal vessels have been damaged irreparably and thrombosed, vasodilative drugs cannot influence the course of the severe pathological process.

Quite the opposite of the above-described method is the use of vasoconstrictive drugs, such as corvasymptone (Fischer and others, 1950; Damato, 1953) and sympathol (Nemetz, 1953; Pillat and Schenk, 1960; Davydova, 1961).

Davydova (1961) used sympathol in treating 24 patients (28 eyes) with good results. It should be noted that most of the patients suffered from eye burns of the I and II degrees.

The mechanism of action of vasoconstrictive drugs is not clear. Fischer *et al.* (1950) contend that the effect of corvasymptone depends on the presence of adrenaline as a component. Hamburger (1958) presumes that relative hyperaemia, resulting in better nutrition of tissues, sets in after the vasoconstrictive effect.

Tartakovskaya (1968, 1970) insists on the treatment with adrenaline, regarding toxic paresis of the capillaries foremost among vascular disorders in eye burns. She considers the vasodilator drugs to be useless in haemostasis and trichangiectasis. The author, however, cites no data of comparative research in the use of vasodilator drugs (acetylcholine, in particular) and adrenaline.

At the same time our clinical observations have shown that even in extensive necrosis of the conjunctiva part of the vessels are in a spastic condition the first few hours after a burn, which may be revealed by making the acetylcholine test. The dilatation of vessels in ischaemic zones and also marked vascular hyperaemia in slightly damaged or intact conjunctiva promotes the active flow of blood to the burnt tissues, improves the supply of nutrients to the cornea and washing out of toxic products forming in a burn. We therefore consider it beneficial to apply vaso-

dilators at the early stages of the eye burn disease. It is of prime importance to apply acetylcholine in correct doses and as soon as possible after the burn (in the form of subconjunctival injections and frequent instillations of a 5 to 10 per cent solution), and discontinue it at the proper moment as the conjunctiva is gradually vascularized.

If we become convinced, however, that after applying acetylcholine in one or two days the vessels are not demonstrated in the area of the deep affection of the conjunctiva and sclera, we shall have to cover the sclera with the lip mucosa after Denig.

To improve circulation in the conjunctiva and ciliary body in severe burns heparin should be included in the complex of therapeutic measures and applied by subconjunctival injections, instillations and in repeated irrigation (Godina, 1972; Bogdashev, 1973; Prantsuz, 1973, and others).

In the Soviet Union subconjunctival injections of autologous blood with penicillin have been used in eye burns since 1957 (Milovidova, 1957; Yaudegide, 1957). This method won popular recognition and to a large extent ousted surgical treatment (particularly Denig's operation) from the arsenal of therapeutic measures (Valova and Rejchrt, 1957; Kulakhmetyeva and Ladyzhinskaya, 1959; Uglova, 1959, 1964; Molnar, 1960; Ershkovich, 1961; Bochkareva and Pastukhova, 1963; Chernova, 1964; Isaeva, 1964; Pavlyuchenko, 1964; Trusov and Rozenkrants, 1966; Kuprianowicz and Cresnel, 1969, and others). In the opinion of most authors, its principal advantage consists in the prevention of symblepharon in severe eye burns.

Many works published recently contain a more reserved assessment of the method. Pokrovskaya and Zelenina (1964) noted that six out of ten cases with III and IV degree burns ended in loss of the eye and total symblepharon, despite vigorous combined treatment including subconjunctival injections of autologous blood with penicillin.

Ilchenko (1964) and Rodigina *et al.* (1964) consider that such treatment cannot be a substitute for Denig's operation in severe burns. They also infer that both Denig's operation and non-surgical methods have a poor effect if the patient delays seeing a doctor and his vision is completely lost.

In cases with extensive necrosis of the conjunctiva Koptsiovskaya (1964) and Lazarenko (1965) prefer using films of fibrin prepared from donor or autologous blood. Chernova

(1967) obtained a good effect in treating alkaline burns with films of fibrin prepared from heterologous blood.

In comparing the results of treatment in two similar groups of patients with eye burns, Preobrazhensky (1965) noted that the addition of injections of autologous blood to the combined non-surgical treatment suggested by Polyak in 1957 had no essential effect on the course and outcome of the burns; for that reason there seem to be no grounds for recommending injections of autologous blood in cases of mass eye burns.

Clinical and morphological studies conducted by Valul and Feher (1967) showed that the use of autologous blood in experimental lime burns accelerates treatment but has no effect on the intensity and size of cicatrization.

One can see on the example of just two cases how opinions on the use of subconjunctival autologous blood injections may differ. Pavlyuchenko (1967) reports that in all patients (100 per cent) treated with autologous blood and penicillin for severe and very severe burns visual acuity was high (from 0.2 to 1.0). According to Savinskaya (1967), who applied combined treatment including injections of autologous blood, visual acuity of 0.5 to 0.6 was attained only in three out of 28 patients with III and IV degree eye burns. In 18 cases visual acuity did not exceed 0.04, in four patients it was at the level of light perception, and in another three, it was zero. Such a marked disparity in the assessment of one and the same method of treatment may obviously be explained first of all by the different approach to determining the degree of the severity of the burn, because it is hardly possible to improve visual acuity to 1.0 and completely avoid severe adhesion between the eyelid and eyeball in particularly severe eye burns. By prescribing rational therapy we may only arrest further spread of the necrotic zone, with which the progressing deterioration of the process is connected, and stimulate the vital activity of preserved or slightly damaged areas of the conjunctiva, cornea and other parts of the eye.

Our experimental research (Nepomyashchaya, 1970) showed that subconjunctival injections of autologous blood in deep extensive eye burns very often contributed to progressive deterioration of the condition of the eyes and intensification of general intoxication in the animals.

These data, and also the distinct inflammatory reaction

occurring from injection of serum or whole blood from burnt animals into the cornea and anterior chamber of a healthy eye, testify to the presence of toxic products in the blood of animals with fresh eye burns capable of having a harmful effect on the course of the pathological process.

It should be mentioned that in recent years we have not applied subconjunctival injections of autologous blood and penicillin in treating eye burns because we became convinced in the apparent advantages of convalescent serum over this method.

In many patients with severe and particularly severe burns subconjunctival injections of autologous blood could not prevent severe complications or even loss of the eye at times. We became convinced in that from our own experience with the method, and by observing many patients sent to the Institute from other medical institutions with severe complications of a burn which had developed despite treatment with injections of autologous blood.

In recent years a considerable role in the development of such complications as ulceration and perforation of the cornea is attached to the effect of colagenases which form in the burnt cornea. It has been demonstrated that cysteine and EDTA are inhibitors of collagenases, and their use in experiments and in clinical practice results in a decrease of the number of these complications (Brown *et al.*, 1969; Gnädinger, *et al.*, 1969; Brown *et al.*, 1972, and others).

## ANTI-INFLAMMATORY THERAPY (SUPPRESSION OF THE INFLAMMATORY PROCESS)

It has been pointed out above that, along with the damage to the outer coats of the eye, there is a rather rapid involvement of the uveal tract (the iris and ciliary body) into the inflammatory process in a burn. The question of using mydriatics in the developed iritis and iridocyclitis is rather complex, however. Severe and particularly severe eye burns are frequently complicated by increase in intraocular pressure at the very early stages of the burn process. The use of atropine considerably promotes the tendency to hypertension and also diminishes the vasodilatating effect of acetylcholine.

At the same time, severe inflammation in the iris and ciliary body, tending to the formation of posterior synechiae, requires the use of mydriatics.

The best remedy in such cases is scopolamine in the form of an 0.25 per cent solution and ointment, which are applied frequently, up to five or six times a day, keeping the pupil dilated. At later stages adrenaline may also be used from time to time, but with great care, since haemorrhages into the anterior chamber may sometimes occur from its use.

When intra-ocular pressure tends to rise, mydriatics should always be combined with common hypotensive measures (fonurite, hypothiazide, diverting measures, application of leeches to the temple, etc.); instillation of pilocarpine may be alternated with the prescription of scopolamine ointment under strict control of the condition of the pupil and intra-ocular pressure.

Employment of anti-inflammatory therapy is closely connected with the phase of the burn disease. Thus, in the first stage, characterized by the prevalence of alteration phenomena, our purpose is to stimulate regenerative processes and development of active hyperaemia of the vessels of the ocular tissues which is attained by means of vasodilators. In the stage when exudative processes are manifest, moreover with the tendency for hyper-regeneration, our efforts must be aimed at suppressing the inflammatory process and at control of corneal vascularization.

Corticosteroids contribute greatly to liquidating the inflammatory process.

Corticosteroids have an anti-inflammatory effect, they inhibit exudative processes and cellular infiltration, prevent the growth of new blood vessels in the cornea to a certain degree and diminish the allergic reaction in eye burns. Most clinical studies on their use cover very few cases and are sometimes occasional; therefore there is no common opinion as yet on the method of their application.

Leachey (1952), Delong and Dolenek (1956), Langer (1956), Magilnitsky (1957), Parkhomovsky and Chistik (1960), Ershkovich (1961), Chernova (1964), Pavlyuchenko (1964) and Kaplunovich (1968) report on the favourable effect of corticosteroids in eye burns.

Ershkovich (1961) considers that injections of cortisone and hydrocortisone should be given immediately after the burn in combination with other types of treatment.

Protopopov *et al.* (1960) are of the opinion that cortisone is beneficial but not in all stages of treatment. When

the inflammatory reaction is weak, tissues are ischaemic and vasodilators have to be used, corticosteroids are harmful. They should be included in the therapeutic complex from the end of the first or the beginning of the second week.

Leachey (1952), Segal *et al.* (1960), Pavlyuchenko (1964), Tartakovskaya (1967) and others share this opinion.

In our view cortisone and hydrocortisone should be used only after total epithelization of the cornea to diminish inflammation and mainly to vascularize the cornea. Even with such careful prescription of corticosteroids, however, we encountered recurrent corneal erosions which healed after these drugs had been discontinued. That is why there should be an individual approach in prescribing corticosteroids for a patient.

Besides corticosteroids, excessive vascularization is controlled with thio-TEPA (triethylene-triamide thiophosphate) in a dilution of 1 : 600 (Lazarenko and Khvoshch, 1970).

Kaplunovich (1969) notes, however, that thio-TEPA leads to de-epithelization and intensification of corneal swelling, and considers the preparation unacceptable for treating eye burns.

Bearing in mind the tendency of the burn process to recurrent inflammation, late ulcerations of the cornea, and so forth, these drugs as well as measures sharply depressing regeneration of eye tissues (such as X-ray therapy, for instance) should be prescribed with great care.

## REMOVAL OF TOXIC PRODUCTS ACCUMULATING IN THE TISSUE AS A RESULT OF NECROTIC DISINTEGRATION

Phenomena of intoxication play a special role in the pathogenesis of eye burns. Accumulation of toxic products is connected with necrotic disintegration of tissues which, in turn, depends both on the initial damage caused by the burn and the degree to which metabolic processes have been disturbed in the tissues following burn. This is why all therapeutic measures stepping up metabolic and regenerative processes in the eye serve to prevent further death of tissues and formation of toxic products.

Several surgical operations undertaken by ophthalmologists both in the early and late stages of the burn process

are aimed at the direct removal of toxic products from eye tissues.

The use of vasodilators promotes the removal of toxins from eye tissues, because restoration of blood flow in the damaged conjunctiva makes it possible not only to supply intensively the nutrients to the burnt areas, but also to evacuate rapidly the accumulated products of necrosis and disturbed metabolism from the tissues.

Homologous serum of burn convalescents which we have been used in the clinic since 1961 proved to be an effective means for neutralizing the harmful influence of toxic products on the course of the pathological process in the eye (Puchkovskaya *et al.*, 1962; Nepomyashchaya, 1965, 1966, 1967; Puchkovskaya *et al.*, 1970).

## IMMUNOTHERAPY (INFLUENCE ON THE PROCESSES OF AUTOSENSITIZATION AND AUTO-INTOXICATION)

The use of directed immunotherapy in clinical practice was based on the strength of experimental studies (described in Chapter II), which showed that immune serum may considerably diminish or completely neutralize the harmful effect of autotoxic reactions on the course of the burn process and prevent its severe complications.

We treated patients with chemical and thermal eye burns with homologous serum of burn convalescents which was supplied by the Central Institute of Haematology and Blood Transfusion (TsOLIPK) and the Odessa blood-transfusion centre. According to the techniques elaborated at TsOLIPK, the serum of burn convalescents is considered active if the donors had suffered II and III degree skin burns on an area of no less than ten per cent of their body surface. The optimum term for obtaining serum from such convalescents is one year after recovery (Koryakina *et al.*, 1960; Kazakova *et al.*, 1965, and others).

According to Kazakova (1963), serologically determined complement-binding antibodies may be found in some cases also at later periods after the burn—up to two and even four years.

The convalescent serum which had been separated from the clot under strict aseptic conditions at the blood-transfusion centre was supplied in flasks of 80 to 100 ml. For convenience of use the serum was poured into sterile ampo-

ules (in amounts of 1 to 2 ml) in special cubicles. The sealed ampoules were subject to bacteriological tests and only on passing could be used for treating patients. The serum may be stored for up to six months in a refrigerator at a temperature of +4 °C or in a frozen state.

We applied homologous serum and plasma of burn convalescents in a dose of 1 ml in daily subconjunctival injections. On the first day the patient received 0.5 to 0.7 ml of serum with a small amount of procaine hydrochloride (0.2 ml of a 1 or 2 per cent solution). The patients usually tolerated the first injection well and in the following days we increased the dose to 1 ml. In the first days after the burn, serum was injected daily; with gradual improvement of the eye's condition injections were given every other day, and then at intervals of two or three days. Patients with moderate burns received six to eight injections on the average, those with severe and particularly severe burns ten to fifteen injections. In individual cases of particularly severe burns treatment consisted of more than twenty injections.

In none of the patients there was an allergic reaction to the serum. It was rapidly resolved from under the conjunctiva and did not hinder observation of the dynamics of the pathological process.

We used the serum of burn convalescents only in the treatment of moderate, severe and particularly severe burns.

The serum was used for treating moderate burns in 106 patients (113 eyes). In practically half the cases (50 eyes) besides the serum the patients received only mydriatics and disinfecting drops and ointments (solutions of sodium sulphacyl, chloramphenicol, streptocide ointment, synthomycin emulsion). Other patients, on complete epithelization of the cornea, also received cortisone or hydrocortisone in drops to prevent corneal vascularization and eliminate remaining inflammation phenomena.

In several cases, on late admission to the hospital and in most severe damage to the eyes in this group, we injected antibiotics intramuscularly or added penicillin or streptomycin to the convalescent serum. Patients with bilateral damage to the eyes, especially those with a severe or particularly severe burn of the second eye, received intravenous infusions of a 40 per cent glucose solution and tissue therapy.

Analysis of the results of treating patients with moderate burns by a therapeutic complex, the main component of which was the serum of burn convalescents, and of those not given injections of immune serum (46 patients; 54 eyes) convinced us of the advantage of the new method of pathogenetic treatment of eye burns.

In cases of moderate burns this advantage had a telling effect primarily in improvement of vision resulting from treatment with convalescent serum, which was due to the rapid elimination of the inflammatory process and development of normal regeneration leading to restoration of vision. In only two patients out of 113 visual acuity remained the same as on admission. In all other cases it improved, moreover in most patients the absolute increase of acuity was considerable.

In the group of patients not given convalescent serum regeneration took a sluggish course. There was no improvement in vision in seven cases out of 54, and in one eye acuity became worse. Visual acuity of 0.85 to 1.0 was obtained only in one third of cases (33.3 per cent), while among patients who received immunotherapy such visual acuity was obtained in 54.8 per cent of cases, despite the fact that the initial indices of vision in this group were worse than in the other one (Table 7).

Most patients with moderate burns were admitted in the first days after the injury. Application of burn convalescent serum yielded favourable results not only in the early stages, but also when patients were admitted much later after they had been treated without success in other medical institutions.

K., a thirty-six-year-old male, was admitted to the Institute nine days after a burn of the right eye with ammonium hydroxide. He was sent by his regional hospital owing to progressing deterioration in the condition of the eye.

On admission: marked irritation of the eye; the cornea in the centre and in the lower half was opacified, grey and there was a deep erosion of irregular shape with loose, uneven edges. Absence of corneal sensitivity. Visual acuity 0.1, not corrected (Fig. 20).

The patient was given six injections of burn convalescent serum with streptomycin under the conjunctiva, five intravenous infusions of glucose with ascorbic acid and topical treatment with albucid (sulphanil acetamide), cod liver oil and scopolamine and streptocide ointments. On discharge there was no irritation, the erosion had epitholized, and the corneal opacities had practically resorbed. Visual acuity 1.0 (Fig. 21).

*Table 7.*

RESULTS OF TREATMENT
OF EYE BURNS OF MODERATE SEVERITY

| Acuity of vision on admission | Total number of eyes | Acuity of vision on discharge | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.01-0.05 | 0.06-0.1 | 0.12-0.2 | 0.25-0.4 | 0.5-0.7 | 0.85-1.0 |
| 0.01-0.05 | 34/12 | 1/— | 3/2 | 3/2 | 6/1 | 6/2 | 15/5 |
| 0.06-0.1 | 44/16 | | —/2 | 3/1 | 9/3 | 10/5 | 22/5 |
| 0.12-0.2 | 19/15 | | —/1 | —/3 | 1/3 | 5/6 | 13/2 |
| 0.25-0.4 | 16/11 | | | | 1/3 | 3/2 | 12/6 |
| Total: | 113/54 | 1/— | 3/5 | 6/6 | 17/10 | 24/15 | 62/18 |

*Note.* Numerator—number of eyes treated with immune serum; denominator—number of eyes treated without serum.

The disparities in the outcomes and course of the pathological process were just as obvious in patients with severe eye burns marked by more extensive and deeper damage to the tissues. This fact particularly illustrates the therapeutic effectiveness of convalescent serum, because if in moderate burns there is still hope for spontaneous recovery of the eye due to the activization of the organism's defence forces, severe burns, in contrast, even with the application of combined therapy (anti-infection, tissue therapy, etc.) are marked by persisting and complicated course and usually terminate with considerable loss of vision.

Bearing in mind that auto-intoxication is merely one, though very important, aspect of the pathological process in the complex pathogenesis of severe eye burns, in all cases of severe and particularly severe eye burns we used combined therapy including vasodilatating agents, mainly

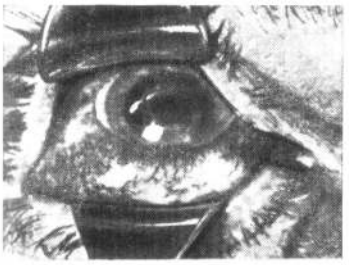

FIG. 20. Patient K. An ammonium burn of the cornea, of moderate severity, the tenth day. Acuity of vision 0.1 without correction.

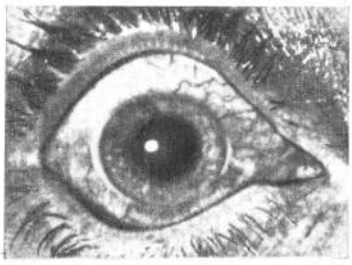

FIG. 21. Patient K. The condition of the eye after treatment on the 23rd day after the burn. The eye not irritated, the cornea is transparent with the exception of an insignificant opacity at the limbus. Acuity of vision 1.0.

acetylcholine in drops and in subconjunctival injections and topical disinfecting solutions and ointments. In most severe cases we prescribed intramuscular injections of antibiotics under control of bacteriological tests, alternated intravenous infusions of 40 per cent glucose and urotropin, or a 10 per cent chloride solution and gave vitamins (vitamins A, B complex and C). After corneal epithelization was completed, we applied cortisone or hydrocortisone in injections and instillations.

In severe burns the serum of burn convalescents was applied to 160 eyes; 35 eyes were treated without serum.

The results of serum treatment were characterized by more rapid liquidation of inflammatory process in the eye, sharp reduction of complications of the burn, stimulation of regeneration processes, which resulted in considerable resorption of corneal opacity and improved visual acuity. Vision improved in 80.6 per cent of patients treated with convalescent serum and only in 45.7 per cent of those who had not received immune therapy (Table 8).

The differences in the course of the pathological process were just as clear-cut in severe eye burns (Table 9). The number of severe complications (corneal infiltrations and ulcers, exudate in the anterior chamber, rise in intra-ocular pressure and perforation of the cornea) in patients not given injections of convalescent serum was fourfold that

*Table 8.*

RESULTS OF TREATMENT OF PATIENTS WITH SEVERE BURNS OF THE EYE

| Acuity of vision on admission | Total number of eyes | Acuity of vision on discharge | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1/∞ pr. incerta | 1/∞ pr. certa | 0.01-0.02 | 0.03-0.05 | 0.06-0.1 | 0.12-0.2 | 0.25-0.4 | 0.5-1.0 |
| 1/∞ pr. incerta<br>1/∞ pr. certa | 57/18 | —/4 | 9/4 | 8/3 | 6/3 | 10/1 | 10/1 | 10/2 | 4/— |
| 0.01-0.02 | 52/9 | 2/— | 3/2 | 3/4 | 6/— | 13/— | 10/3 | 5/— | 10/— |
| 0.03-0.05 | 37/5 | — | 1/1 | 2/1 | 5/1 | 3/2 | 9/— | 6/— | 11/— |
| 0.06-0.1 | 12/3 | | 1/1 | 1/1 | | 4/— | 2/— | —/1 | 4/— |
| 0.12-0.2 | 2/— | | | | | | | | 2/— |
| Total | 160/35 | 2/4 | 14/8 | 14/9 | 17/4 | 30/3 | 31/4 | 21/3 | 31/— |

See note to Table 7.

in patients treated with serum (64.6 and 15.8 per cent of cases, respectively), and in some cases two or three complications simultaneously occurred in one and the same eye, e.g. hypopyon and increased intra-ocular pressure, and so on.

More rapid liquidation of inflammation and a decrease in the number of complications resulted in the reduction of average time of hospital-stay. The average period of hospital-stay was 37.8 days among patients with severe

*Table 9.*

FREQUENCY OF COMPLICATIONS OF THE EYE BURN DISEASE AMONG PATIENTS TREATED WITH CONVALESCENT SERUM AND IN THE CONTROL GROUP

| Group of patients and type of therapy applied | Total number of eyes | Complications (number of eyes) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Without complications | Persistent corneal erosions and ulcerations | Corneal infiltrates | Partial resorption of the cornea | Exudate in the anterior chamber | Increased intra-ocular pressure |
| Group of patients who were given injections of burn convalescent serum + complex treatment | 160 | 139 (84.2%) | 4 | 3 | — | 7 | 14 |
| Control group of patients, who received complex treatment without burn convalescent serum | 35 | 11 (35.4%) | 13 | 6 | 3 | 4 | 5 |

eye burns treated with convalescent serum, and 57.3 days (more by 19.5 days) in the group of patients who had not received serum.

This difference in the results of treatment of severe eye burns is possible to link, as we see it, with the antitoxic properties of burn convalescent serum, manifested in its topical application.

Our study showed that the earlier treatment with immune serum was begun, the better was the ultimate vision of the patient.

M., a twenty-six-year-old male, was admitted to the Institute a few hours after a burn of the right eye with carbide. On admission the conjunctiva around the limbus was ischaemic with areas of necrosis, the limbus was pale. The cornea was opacified like a densely opaque glass. Sensitivity was absent. The pupil was outlined, there was no reflex from the fundus oculi. Visual acuity 0.02 (Fig. 22). The patient was given frequent instillations of a 10 per cent solution of acetylcholine, sodium sulphacyl, cod liver oil and scopolamine ointment. Serum of burn convalescent was injected under the conjunctiva in doses of 0.7-1.0 ml, 14 injections in all. Intravenous in-

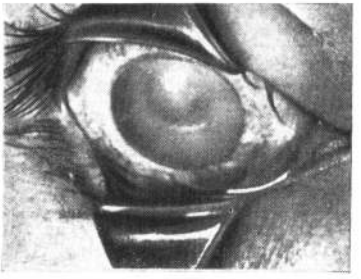

FIG. 22. Patient M. A severe burn of the conjunctiva and cornea with carbide, the second day. Acuity of vision 0.02.

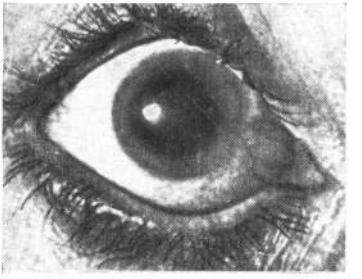

FIG. 23. Patient M. The condition of the eye after treatment. Acuity of vision 0.2, with diaphragm 0.5.

fusions of a 40 per cent glucose solution and injections of aloe extract were given. On discharge there was practically no irritation of the eye, the conjunctiva was smooth, there were no adhesions, the cornea was almost transparent in the centre and in the lateral half. Mild opacities with a small number of vessels were seen in its medial half. A bright reflex was seen from the fundus oculi which showed no abnormalities. The pupil was wide, visual acuity 0.2, with diaphragm 0.5 (Fig. 23).

The burn process followed a similar course in patient K. (Figs. 24-25).

In some cases prescription of convalescent serum promoted improvement in severe complications of the burn.

S., a twenty-three-year-old male (case history No. 42623), was treated at the Institute for extensive corneal infiltrate and severe burn with concentrated sulphuric acid of the skin of the right eyelids, conjunctiva and cornea.

He was admitted to the Institute on the eleventh day after the burn. Before that he had been treated at a local hospital with daily subconjunctival injections of autologous blood and penicillin and topical applications of Hippophae oil, vitamins and Synthomycin (chloramphenicol) emulsion.

He was sent to the Institute owing to the progressive worsening of the condition of the eye. Left eye: total necrosis and rejection of the conjunctiva around the limbus, intensive corneal opacity, exudate in the anterior chamber, opacity of the lens. Denig's operation was performed, the cornea and sclera were covered with corneoscleral transplant; the edges of the eyelids were sutured. The process terminated in the formation of total symblepharon of both eyelids and ankyloblepharon.

Right eye: the superior fornix was shortened, the other parts of the conjunctiva loose and purple-coloured due to the autologous blood.

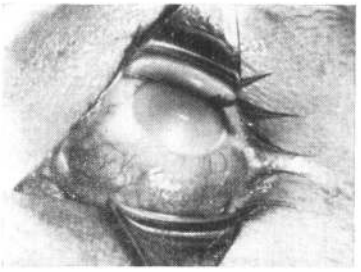

FIG. 24. Patient K. A severe burn of the cornea and conjunctiva with caustic soda. Acuity of vision 0.01.

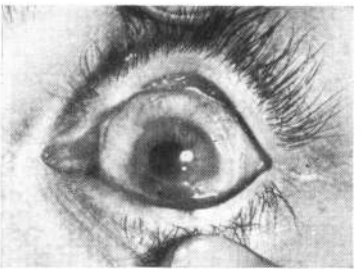

FIG. 25. Patient K. The condition of the eye after treatment. Acuity of vision 0.4.

The limbus in the lower half was white, no vessels were seen; there was diffuse opacity of the whole cornea with an extensive infiltrate in its lower portion. Visual acuity—perception of hand at the face (Fig. 26).

The patient received combined therapy, including injections of burn convalescent serum. On discharge the conjunctiva of the right eye had slight cicatricial changes, the fornices were sufficiently deep. The cornea in the upper third and lateral part was almost transparent, there was an intensive vascular opacity in its lower portion in the place of the infiltrate. Visual acuity 0.07 with a wide pupil and diaphragm of 0.25 (Fig. 27).

The group of particularly severe burns represented mostly cases of irreversible damage, characterized mainly by necrosis. Treatment of these burns became still more difficult owing to the late admission of the patients who were sent from other medical institutions after unsuccessful nonsurgical and surgical treatment applied there (mainly injections of autologous blood); the pathological process was sharply aggravated and in most cases called for surgery.

What is the effect of injections of burn convalescent serum on the course and outcome of the pathological process in particularly severe eye burns? In many cases of moderate burns we were able to attain complete restoration of corneal transparency and normal visual acuity, whereas in severe burns with deep corneal lesions, high visual acuity was rare, while its improvement even by 0.1 to 0.2 may be considered a good result.

FIG. 26. Patient S. A severe burn of the eye with concentrated sulphuric acid, the twelfth day. Extensive corneal infiltrate. Acuity of vision—the movement of hand seen close to face.

FIG. 27. Patient S. The condition of the eye after treatment. Acuity of vision 0.07.

Particularly severe burns are mainly characterized by extensive necrotic changes in the ocular tissues and pathological regeneration during healing. For that reason in such cases we considered the outcome to be favourable even when small visual acuity was restored, the eyeball remained intact and already developed complications leading to loss of vision were prevented or eliminated.

Only 77 out of 168 patients with particularly severe burns were admitted no later than the tenth day after the accident. The other patients were admitted between the eleventh day and the sixth month after the burn. Most of them had severe complications such as copious exudation into the anterior chamber, ulcers, infiltrates and thinning of the cornea, lens opacity and increased intra-ocular pressure. The visual acuity in such cases did not exceed light perception with correct and incorrect light projection.

Even in relatively favourable cases particularly severe burns were distinguished by persisting recurrent erosions and formation of adhesions between the eyelids and the eyeball because of excessive growth of connective tissue.

Keratoplasty was undertaken in 25 cases, in 14 of them for thinning of the cornea found on admission; in 5 cases

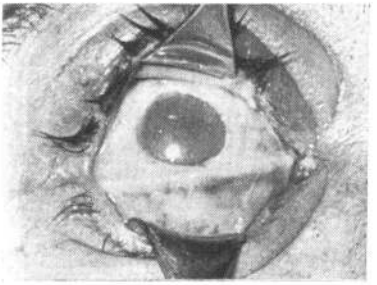

FIG. 28. Patient O. The right eye after a particularly severe burn with 90 per cent acetic acid.

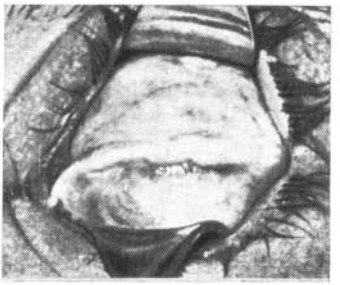

FIG. 29. Patient O. The left eye after a particularly severe burn with 90 per cent acetic acid. Acuity of vision—light perception with correct projection.

the cornea became thin during treatment, while in six cases therapeutic lamellar transplantation was performed in persisting erosions.

Tectonic keratoplasty performed on a background of combined therapy, including immune serum, helped preserve the eyeball intact in all patients with the exception of two, in whom the process terminated in shrinkage of the eyeball despite repeated operations.

O., a male, was sent to the Filatov Institute of Eye Diseases and Tissue Therapy in view of the hazard of corneal resorption after a burn with 90 per cent acetic acid. He was admitted on the fourth day of the burn. Inspection showed that the conjunctiva of both eyes and eyelids was necrotized, loose, and covered with thick necrotic films which hid the whole cornea on the left eye. The cornea was cloudy and grey; after removal of the films from the left eye the anterior corneal layers proved loose (when tested with a probe). Visual acuity of both eyes—light perception with correct light projection (Figs. 28-29).

Combined non-surgical therapy was applied, including 25 subconjunctival injections of burn convalescent serum with streptomycin. The condition of the eye improved considerably. The conjunctiva of both eyes became vascularized and the forming scars were fine and did not require surgical treatment.

The cornea epithelized and its transparency somewhat improved although there were still a large number of vessels in it. Visual acuity increased to 0.03 in the right eye and 0.02 in the left (Figs. 30, 31).

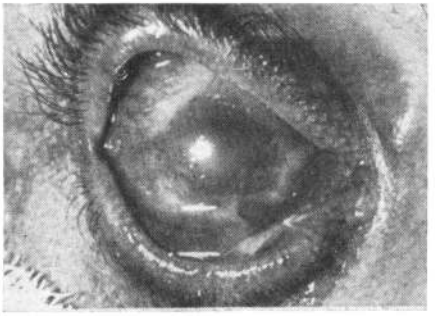

FIG. 30. Patient O. The right eye after treatment. Acuity of vision 0.03.

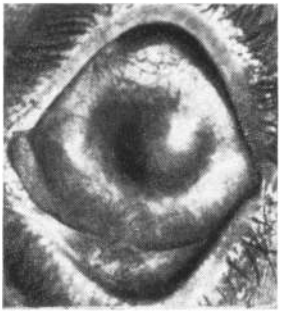

FIG. 31. Patient O. The left eye after treatment. Acuity of vision 0.02.

The case cited is distinguished by the absence of complications throughout the whole period of the disease and by good regeneration of the conjunctiva and cornea due to the treatment applied.

A good outcome of the burn was also encountered in patient G. admitted to the Institute four hours after a burn of both eyes with carbide (Figs. 32-33).

Analysis of the results showed that the inclusion of convalescent serum into the complex of therapeutic measures in particularly severe eye burns is conducive in some cases to the prevention of severe complications and the preservation or certain improvement of vision, even in severe lesions which at first glance seemed hopeless. The best visual acuity was observed in cases where at least the smallest area of more or less viable corneal tissue had been preserved, and when the necrosis of the conjunctiva extended over more than half but not over all the surface of the eyeball.

The less damaged areas served as a kind of source for further tissue regeneration, from which epithelization of the cornea and growth of vessels into the necrotic conjunctival areas began. In total necrosis of the eyeball conjunctiva the sources of corneal nutrition were impaired, the toxic effect of the damaged tissues increased, and processes of rehabilitation were greatly delayed. Thinning of the cornea progressed and in some cases there was its partial perforation.

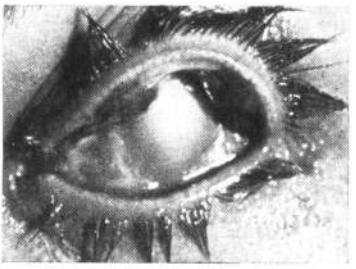

FIG. 32. Patient G. A particularly severe corneal burn with carbide. Acuity of vision 0.02.

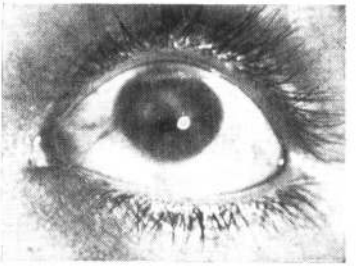

FIG. 33. Patient G. The condition of the eye five years after the injury had occurred. Acuity of vision 0.25.

Very often patients with particularly severe eye burns needed surgical treatment later, because in most cases the necrotic lesions of the conjunctiva terminated in cicatricial adhesions between the eyelids and the eyeball.

Extensive or total symblepharon was encountered as the result of burns in 35 eyes, partial symblepharon—in 9 eyes; 17 eyes had scars which did not require surgical treatment; in 16 eyes, mainly after ammonium burns, the fornices were normal (the analysis covers 77 eyes where treatment was begun at comparatively early periods).

Thus, study of the burn process in the clinic showed that moderate, severe and particularly severe eye burns lead to the development of a severe pathological process which requires active therapy for its liquidation and restoration of vision.

Treatment may be limited to the prescription of disinfecting drops and ointments only in mild eye burns, but even then the patient must be under a doctor's observation.

The serum of patients recovering from a skin burn can be used for treating moderate burns as an independent method which includes, besides immune therapy, the use of disinfectants.

More severe eye burns require combined therapy, which, in addition to injections of convalescent serum, should include vasodilators, corticosteroids, antibiotics, tissue therapy, vitamins, etc. In particularly severe burns, it is

necessary to combine complex non-surgical therapy with surgical measures.

Blood substitutes (haemodes, Neocompensan, VK-8) have also been suggested as non-specific detoxicants (Lapshina, 1973; Semenov, 1973).

## CONTROL OF REMOTE COMPLICATIONS (RECURRENT INFLAMMATION)

Patients who suffered moderate, severe and particularly severe eye burns should be examined regularly by an ophthalmologist for a long period of follow-up, because they often require repeated resorption and desensitizing therapy and also surgery for removal of the sequelae of the burn. At remote periods after discharge from the hospital a burn process is characterized by a recurrent inflammation, which may aggravate the condition of the eye and cause progressively diminishing vision.

Remote follow-up of patients who had been treated with convalescent serum showed that in 78.3 per cent of cases vision did not deteriorate, and in many cases (40 per cent) it even improved after longer periods of time after the burn. This is evidence that the regenerative processes in the corneal tissue do not terminate with the complete epithelization and cessation of inflammation in the eye.

Tissue therapy prescribed for all patients after their discharge from the hospital considerably improved vision. It comprised daily subcutaneous injections of aloe extract, FiBS[1] or torfot[2] in a dose of 1 ml to a total of 30 injections. Treatment was carried out three times a year with an interval of six to eight weeks.

An excellent measure for resorbing residual corneal opacities after a burn are subconjunctival injections of 0.3 to 0.4 ml of torfot every other day (and sometimes daily), the treatment consisting of 15 to 20 injections (Puchkovskaya *et al.*, 1968).

In cases with persisting photophobia or frequent recurrent inflammation in the eye, the patients are given repeated treatment with injections of convalescent serum (0.4

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[1]Biogenic stimulator prepared from estuarine mud and containing cinnamon acid and coumarine.

[2]Peat distillation product.

to 0.5 ml) under the conjunctiva every other day, to a total of 12 to 15 injections, which possesses a desensitizing effect (Puchkovskaya *et al.*, 1970).

Vision grew worse in 21.7 per cent of cases, mostly in patients with particularly severe burns. The main causes of diminished vision were intensification of cicatricial adhesions between the eyelids and eyeball, and growth of cicatricial tissue over the cornea, recurrent inflammation, corneal erosions and secondary glaucoma.

In most cases all these changes require surgical treatment which will be discussed below.

CHAPTER VI

# Surgical Treatment of Eye Burns

The ophthalmologists have attempted to influence the course of the burn process by surgical means for a long time.

McLaughlin (1946, 1952) described his good results obtained in total removal of the epithelium from the burnt corneal surface immediately after irrigation of the burnt eye. Other researchers, however, failed to achieve good results using this method.

To reduce tension in burnt tissues and swiftly get rid of the chemical substance accumulated in the subconjunctival tissue, and remove the toxic transsudate, Passow (1939, 1955) suggested making incisions in the conjunctiva and then separating it with a spatula from the sclera. This operation found adherents (Polyak, 1957, 1961; Buchmann and Frank, 1958; Hollwich, 1958; Chernova, 1965; Kishkina, 1969, and others).

Individual authors, bearing in mind the shortlived effect of Passow's operation, recommend combining incisions of the conjunctiva with vasodilators (Oansea and Vasinca, 1964), amnion implantation (Uglova, 1964), or paracentesis (Dao Suang Cha, 1964; Kaplunovich, 1964).

Our clinical experience showed that Passow's operation has no noticeable effect on the course of the burn process in severe and particularly severe eye lesions.

In 1910 Pichler suggested performing early corneal paracentesis in chemical eye burns to remove chemical substances from the anterior chamber. This method won over many followers. Berezinskaya (1938, 1947), Orlowski and Wekka (1956), Parkhomenko (1958, 1960), Dao Suang Cha (1964) and Kaplunovich (1964) find it necessary to apply early paracentesis in combination with other methods of treatment. Other authors (Grant, 1950; Duke-Elder, 1954;

Ilchenko, 1964) do not note any beneficial effect of paracentesis.

There were many patients at the Filatov Institute who had been previously treated by means of early paracentesis; the condition of the affected eye on admission, however, was very severe. In patients with increased intra-ocular pressure we often observed anterior synechiae at the site of paracentesis and the development of partial corneal staphyloma. We do not perform paracentesis in ocular burns now.

To restore perilimbal circulation and prevent adhesions between the eyelid and eyeball, Denig (1912) proposed removal of the necrotized parts of the conjunctiva in the first 24 to 36 hours after the burn and transplantation of mucosal flaps taken from the patient's mouth to the vacant sites. Filatov (1931) and Thies (1938) noted the favourable effect of Denig's operation. Zenkina (1939), Dashevsky and Marmorstein (1940) transplanted mucous membrane taken from cadaver. Using the method of angioradiography, Pavlyuchenko (1956, 1958) showed that Denig's operation promoted quicker restoration of the perilimbal network and better outcomes. In considerable necrosis of the conjunctiva Polyak (1957, 1961), Vejdovsky (1963), Ilchenko (1964), Rodigina *et al.*, (1964) and Heinc (1967) consider it necessary to transplant the mucosa according to Denig's technique.

At the same time a tendency was noted among some authors to reject Denig's operation (Wagenaar, 1952; Milovidova, 1957; Isaeva, 1960; Kaznelson, 1962; Protopopov and Galchin, 1964, and others).

In recent years we have also rarely resorted to Denig's transplantation of the mucous membrane. In deep necrosis of the conjunctiva, however, the sclera must be covered without fail with some tissue, because if it is exposed for considerable time, the adjacent corneal areas are unfavourably affected and opacities form, as a rule. Of all the tissues that were proposed for the purpose, the patient's oral mucosa is nonetheless the most accessible and effective.

The time of transplantation specified by Denig (24 to 36 hours after the burn) must be adhered to meticulously, because later transplantation may end in the rejection of the flaps and a vigorous inflammatory reaction in the affe-

cted eye, although we did not always observe such reaction in late transplantation. The method for fixation of the flap is of topmost significance. Denig and other authors usually stitched the mucosal flap to the conjunctiva on the border of the necrotic area. Such a method causes displacement and thickening of the flap. It is essential to attach the mucosa with sutures passed through the anterior layers of the sclera drawing the flap tightly over its surface. With this method we never observed displacement and thickening of the transplanted mucosa.

As for the redness of the transplanted mucosa, which some authors regard as a shortcoming, this is easily eliminated later. In a few months the transplanted mucosa in the area of the palpebral fissure on both sides of the cornea may be resected and the wound surface covered with the conjunctiva taken from the adjoining areas of the eyeball.

The homologous oral mucosa preserved in Belyakov's solution (see Chapter VIII) may also be transplanted. A flap of conjunctiva taken from the contralateral eye may also be used, although patients are reluctant to consent to this manipulation. It should be noted that complications are possible (shortening of the fornix, formation of adhesions) since rather large flaps are needed. The conjunctiva should not be resected in the region of the retrotarsal fold because this may result in considerable shortening of the fornix.

We tried using the conjunctiva taken from the eyes of cadaver, as recommended by Averbakh (1937) and Morozova (1971), and were convinced that this is possible only for covering small areas.

Keratoplasty occupies a prominent place in surgical treatment of eye burns and their sequelae. To be sure, it may prove to be acutely necessary and the only effective operation beginning with the first day of the burn, in the duration of the whole burn process, and then when sequelae develop.

The methods of corneal transplantation according to the purpose and type of the operation are shown in Table 10.

It can be seen from the Table that various types of keratoplasty are indicated throughout the burn process and later with the development of its sequelae.

Let us dwell on operations for corneal transplantation which are indicated in the early periods after the burn.

*Table 10.*

TYPES OF KERATOPLASTY INDICATED IN EYE BURNS AND THEIR SEQUELAE

| Purpose of keratoplasty | Type of operation | Time of operation after burn |
|---|---|---|
| Emergency | Total lamellar | Within the first 24 hours |
| Early tectonic | Lamellar, perforating and lamellar-perforating | Throughout the whole burn process |
| Early therapeutic | Lamellar and surface lamellar | Throughout the whole burn process |
| Optical | Partial, total, almost total lamellar and peripheral lamellar | In 12 months and later |

## URGENT KERATOPLASTY

As it was mentioned above, besides local disturbances caused by the damage to the tissues, a major role in the pathogenesis of eye burns belongs to the organism's general reactions to the products of necrosis and tissue disintegration in the focus of affection. Being absorbed from the burnt area, they become a source of intoxication of the organism, while developing autosensitization promotes the recurrent exacerbations of the pathological process.

Surgical experience has proved that timely and radical removal of necrotic and non-viable tissues from the area of the burn diminishes the possibility of auto-intoxication, infection and other complications, and promotes regenerative processes. That is why it could be assumed that the surgical method of debridement (necrectomy with subsequent keratoplasty) would possibly also be preferable in severe eye burns, because in such cases non-surgical therapy alone is often incapable of arresting the advance of the process and proves not sufficiently effective.

As far back as in 1931, in thermal burns of the conjunctiva and cornea Filatov, in addition to Denig's operation, also performed homoplastic transplantation of the epithelium with thin layers of corneal tissue on the burnt surface of the cornea. Dolenek (1952), Zolotareva (1957), Vejdovsky and Heinc (1964), Goldfeld (1967), Alberth (1968), Heinc (1969) and others also employed lamellar transplantation

of the cornea in severe burns. But they performed it only after all acute symptoms had vanished.

If we agree, however, with the need and significance of surgical debridement of the cornea after severe eye burns then it must be radical and carried out in the earliest possible time after the accident.

## EXPERIMENTAL RESEARCH

We performed basic experimental research into urgent lamellar keratoplasty on more than 400 rabbits (Puchkovskaya and Muchnik, 1964).

Burns of the cornea in the animals were inflicted by sulphuric acid, ammonium hydroxide, lime and also by a thermal agent. Extensive corneal burns with 20 per cent sulphuric acid took a severe course. In most control animals persistent clouding of the cornea developed and in some cases the inflammatory process terminated in resorption of the ocular tissues.

In urgent keratoplasty the affected layer of the whole cornea was removed down to the transparent layers and total lamellar transplantation was performed, i.e. a transplant of anterior corneal layers was grafted onto the wound surface. In more than half of the animals operated on in the first 24 hours after the burn, complete taking of the transplant occurred with its transparency completely or almost completely retained. Operations performed in the immediate six hours after the burn proved particularly effective.

Burns by 40 per cent sulphuric acid caused very severe lesions of the eyes. The inflammatory process in the control rabbits was attended with intensive leukocytic infiltration which led to the resorption of the corneal tissue and then to perforation of the eyeball in all of them. In these burns, which in the absence of treatment inevitably terminated in the loss of the eye, total lamellar corneal transplantation within the first six hours after the burn also resulted in good taking of the transplant in 70 per cent of the animals with complete, or almost complete restoration of corneal transparency (Fig. 34). Operations carried out later than 24 hours proved ineffective, resulting in the loss of all eyes.

Urgent lamellar transplantation of the cornea also had a beneficial effect in eye burns by ammonium hydroxide.

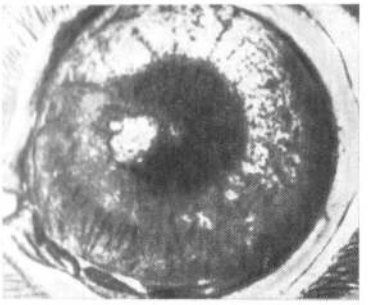


FIG. 34. The eye of a rabbit burnt with 40 per cent sulphuric acid. Urgent lamellar keratoplasty was performed six hours after the burn.

The burning agent was applied in two concentrations—10 and 25 per cent solutions.

In burns by a 10 per cent ammonium hydroxide solution, an operation performed within the first six hours terminated in complete restoration of corneal transparency in 40 per cent of cases, in 20 per cent the transplant remained semi-transparent. In operations carried out 8 to 24 hours after the burn the percentage of complete or almost complete taking of the transplants came close to 30. In 90 per cent of control animals with such burns the cornea grew opaque or resorbed.

The severest eye burns induced by 25 per cent ammonium hydroxide terminated in opacity and resorption of the cornea in all control rabbits. But urgent lamellar keratoplasty performed in the immediate six hours after the burn resulted in full-value taking with complete or almost complete restoration of corneal transparency in 36.4 per cent of cases and in about 20 per cent of cases when the operation was carried out within 8 to 24 hours.

Urgent keratoplasty performed within six to ten hours after a lime burn had a favourable outcome in 50 per cent of the experimental animals; the transplants remained completely, or almost completely transparent. An operation undertaken in 16 to 24 hours provided full-value taking of the transplant with preservation of its transparency in 35.7 per cent of cases. In control animals with lime burns,

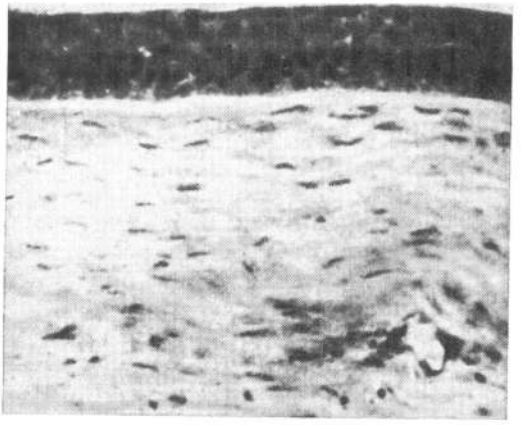


FIG. 35. Histological section of the cornea two months and twenty days after urgent lamellar keratoplasty had been performed within sixteen hours after a thermal burn of the cornea had occurred. The structure of the transplant is approximately normal.

83.4 per cent had perforation of the cornea resulting in loss of the eye.

Burns by molten metal (Wood's alloy heated to 100°C) produced severe lesions in the corneal tissue with marked destruction of all its layers. The involved corneal areas became marble-white in colour. In the immediate hours after the burn, disturbances were found not only in the epithelium and stroma of the cornea, but also in Descemet's membrane and in the endothelium. In control animals the cornea grew opaque or was fused in 93 per cent of cases. The picture is quite different in rabbits in which urgent lamellar keratoplasty was performed in the immediate hours after the burn.

Thus, an operation carried out within the first ten hours after a burn promotes full-value taking of the transplant with preserved transparency in 46.4 per cent of cases

Microscopic examination of specimens of the cornea of eyes enucleated in various periods after the operation revealed that in those cases, when the transplant fully restores its transparency after the operation, the structure of the cornea hardly differs from the norm (Fig. 35).

Experimental observations thus testify that urgent lamellar keratoplasty of the cornea with preliminary necrectomy undertaken very early (within 24 hours) after severe burns with acids, alkalis and high temperature promotes delaying of the destructive process and preserving of the eye and transparency of the cornea in a large percentage of cases. They also confirm that even in severe burns viable elements remain in the cornea which, in favourable conditions, may restore their morphological and functional structure. The earlier the surgical intervention is performed, the better is the outcome of the pathological process.

Other authors also confirmed in experiments the efficacy of early lamellar keratoplasty in eye burns (Preobrazhensky, 1964; Dzhaliashvili *et al.*, 1966).

On the grounds of experimental research lamellar keratoplasty in severe eye burns may be recommended as an urgent operation, which is best performed in the immediate hours after the accident.

## CLINICAL OBSERVATIONS

The clinical observations available (Preobrazhensky, 1964; Lazarenko, 1965; Alberth, 1966, 1968; Puchkovskaya and Nepomyashchaya, 1966) confirm the effectiveness of urgent lamellar keratoplasty in eye burns. But there are still few clinical observations on urgent keratoplasty performed within 24 hours after the burn, which is explained by the fact that in the first hours after the accident the condition of the burnt cornea and the eye often seems to be less severe than they actually are, and it is only later that the very severe affection becomes apparent. As a consequence it is not always easy to decide upon urgent transplantation immediately after the burn. There are also data on the complications in lamellar keratoplasty performed for severe eye burns (Lazarenko, 1969, and others).

Unfortunately, there are still no reliable methods for determining the degree of the severity of the burn in the immediate hours after the accident. Steps have been taken to develop such tests (Puchkovskaya *et al.*, 1970) but they require further research.

The absence of precise methods and the impossibility of correctly determining the severity of the affection on the

spot create difficulties for wider application of urgent keratoplasty in clinical conditions.

With regard to the operative techniques, urgent keratoplasty belongs to total lamellar transplantation of the cornea described in detail in Chapter VIII.

It is necessary to elaborate precise methods for determining the severity of the burn and conduct further clinical observations for developing clear-cut indications for urgent lamellar keratoplasty.

### EARLY TECTONIC CORNEAL TRANSPLANTATION

Sometimes deep ulceration or drastic thinning of the cornea due to resorption of its anterior layers may occur even at the earliest periods of particularly severe eye burns.

As it has been pointed out in previous chapters such a condition is extremely hazardous and calls for immediate action, because the cornea may be perforated at any moment. It is essential to take measures before the perforation has occurred and to spare no effort to prevent it.

We believe that perforation of the cornea, prolapse of the lens or other ocular media must never occur in practice. If it does, it means that treatment had been insufficiently active and that keratoplasty was not performed to strengthen the cornea when the first signs of its thinning out had just appeared.

The type of keratoplasty in ulcerations and defects of the cornea depends on the site of the defect and the condition of the cornea of the affected eye. If there is thinning, or deep ulceration without perforation, then the most effective method will be lamellar or, better still, surface lamellar keratoplasty which will be discussed below.

In perforation of a small diameter up to 1 mm the defect may be closed by partial lamellar keratoplasty (Bushmich, 1947; Levtyukh, 1966). In such cases we have recently used superficial lamellar keratoplasty. It should be borne in mind that the iris must be excised simultaneously if it is fused with the edge of the opening, otherwise the fistula may recur. Iridectomy is performed by the routine method prior to lamellar transplantation of the cornea. Should the diameter of the perforating defect in the corneal tissue exceed 1 mm, it is necessary to undertake total perforating or lamellar-perforating keratoplasty.

If the corneal tissue around the perforation opening is not eroded, it is possible to perform a routine partial-perforating transplantation, i.e. to cut a transplant from the cornea of an eye preserved at low temperature, and try to refresh carefully the edges of the opening in the affected cornea with a scraper or Graefe's knife, and then to fit the transplant into the opening in the cornea and secure it in place with absorbable edge-to-edge sutures or with an egg film and Elschnig's overlay sutures.

After a burn, however, the corneal tissue surrounding the perforation opening very rarely stays unaltered, due to which lamellar-perforating transplantation of the cornea has to be undertaken more often.

The techniques of lamellar-perforating keratoplasty with a mushroom-shaped transplant are described by Yushko (1964), Franceschetti (1951) and other authors.

A mushroom-shaped transplant is tailored beforehand. If the perforation opening in the cornea is eccentric, the posterior layers are trephined in line with its position. The transplant is then fitted so that its 'pillar' (the part containing all the corneal layers) plugs the perforation opening. The edges of the transplant are sutured to the limbal episclera.

It should be underscored that the attachment of the mushroom-shaped transplant is not an easy task, because its 'pillar' is not thick (0.3-0.4 mm); so it is difficult to fit it closely into the opening without it being displaced and to sew it to the sclera in the region of the limbus. Only in that case will the restoration of the anterior chamber and success of the operation be obtained.

We developed therefore the techniques of tectonic corneal transplantation using two transplants (Puchkovskaya, 1971). One of them serves as a 'plug' for the opening, while the other, a lamellar one, is grafted onto the eroded corneal surface simultaneously securing the 'plug' transplant.

The operation is carried out as follows. The epithelium is scraped off the anterior surface of the cornea. The edges of the corneal opening are carefully refreshed. If there is an anterior synechia in the area of the opening, iridectomy is first carried out and the adhesions of the iris in the region of the fistula are dissected. There is often a thin membrane in the opening corresponding to the posterior

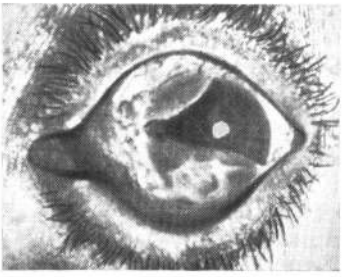


FIG. 36. Patient D. The left eye a week after an operation of tectonic keratoplasty has been performed with two transplants to repair a 4-mm defect in the cornea. Above is an additional lamellar transplant for repairing the marginal ulcer of the cornea.

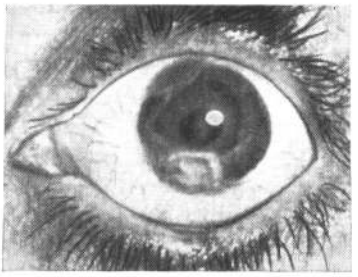


FIG. 37. Patient D. The same eye four months after tectonic keratoplasty with two transplants had been performed. The superficial transplants have resorbed to a considerable degree. A slightly opacified 4-mm 'plug' can be seen at 6 o'clock 1.0 to 1.5 mm from the limbus. The anterior chamber is of good depth, the pupil is round, visual acuity 0.8.

corneal layers; it should not be removed. Two transplants are then tailored. One, with the diameter of the penetrating corneal defect, is excised with a trephine of the corresponding size. The transplant comprises all the corneal layers with the exception of the anterior epithelium which is removed beforehand from the surface of the preserved donor cornea. The second, lamellar, transplant comprises the anterior corneal layers and its size and shape depend on the location and size of the defect. The first transplant is fitted like a plug into the defect with the endothelium facing the anterior chamber. It can be secured in place with two superficial absorbable sutures passed through the anterior layers of the transplant and superficial layers of the cornea around the defect. In this case one can be absolutely sure that the transplant will not be displaced from the opening. The second, lamellar, transplant is placed on the cornea so that it covers the 'plug' transplant and is stitched with absorbable sutures to the episclera or sclera of the limbus. The presence of endothelium in the first transplant provides good conditions for successful closure of the fistula.

The following case illustrates the efficacy of tectonic keratoplasty with two transplants.

D., a female was admitted to the Institute with an ulcer and perforating defect in the cornea and prolapse of the iris of the left eye. The right eye was healthy. Perforation of the cornea had occurred three days previously. The patient was immediately taken to the operating theatre. Prior to the operation her eye had not been photographed. The corneal defect located at the bottom at the limbus was 4 mm in diameter. The prolapsed iris formed a bulge 3 mm high. After the epithelium had been scraped off and the prolapsed iris reduced, a 4-mm transplant was fitted into the opening and fastened in place with 2 superficial absorbable sutures. A lamellar band transplant was applied over it on the lower half of the cornea and secured to the limbus. Since there were corneal ulcerations at 11 o'clock another band lamellar transplant was applied (Fig. 36). The anterior chamber was restored while the patient was still on the operating table; the pupil was round. A month later the lamellar transplants began resorbing and in four months they had been practically resorbed. Fig. 37 shows a somewhat cloudy 4-mm 'plug' transplant. The pupil is round; visual acuity of the left eye 0.8.

With this method successful results may be obtained even when there are large perforating corneal defects in processes of various aetiology.

### EARLY THERAPEUTIC CORNEAL TRANSPLANTATION

Therapeutic keratoplasty may be necessary from the first days of the burn process. Non-healing erosions and ulcers, fusion of the cornea, hypopyon, deep infiltrates, and considerable inflammatory reaction in the presence of changes in the cornea—in all such cases therapeutic transplantation of the cornea may be of immense benefit. This may be partial, subtotal or total lamellar keratoplasty the techniques of which are described in Chapter VIII.

In recent years we have been widely using so-called superficial therapeutic transplantation of the cornea (Puchkovskaya, 1971). It is distinguished from the commonly performed lamellar keratoplasty in that the anterior corneal layers of the eye operated on are not removed, while the lamellar transplant (comprising the anterior layers of the cornea) is grafted directly onto the surface of the affected cornea from which only the epithelium had been scraped. In this operation the lamellar transplant serves as a therapeutic biological covering under which regeneration and

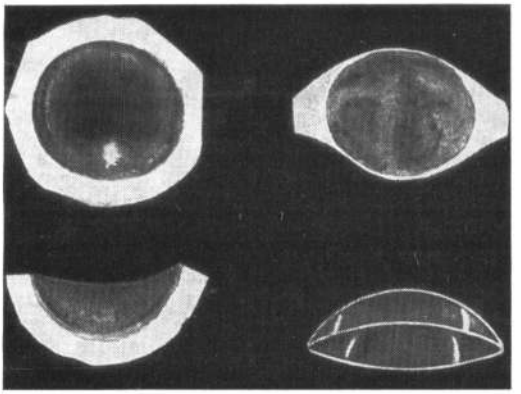


FIG. 38. The shape of lamellar transplants with scleral flaps, with and without the border of the sclera for therapeutic superficial keratoplasty.

restoration of the corneal tissues take place. The favourable effect of therapeutic keratoplasty can to a large degree be explained by the fact that cornea preserved at low temperatures is always used. Undoubtedly it is also of prime significance that precisely corneal tissue is transplanted.

The main stages of an operation for therapeutic superficial transplantation of the cornea are as follows.

1. Preparation of the operative field, akinesia, retrobulbar and epibulbar anaesthesia; bridle suture is applied to the superior straight muscle.

2. Tailoring the transplant from the cornea of the donor's eye. Its shape may vary depending on the size and location of the pathological focus in the cornea. Bearing in mind that after a burn the corneal tissues are often loose and changed, it is very convenient to use lamellar transplants with flaps or the border of the sclera by means of which they are stitched to the sclera. The transplants may be like ribbons, crescent-shaped or of any other shape (Fig. 38).

The border of the transplant is marked with a scraper (non-perforating cut). If a transplant consisting of the anterior layers of the whole cornea with a scleral border is tailored, a circular incision is made in the sclera at a distance of 2 to 3 mm from the limbus and the sclera is sepa-

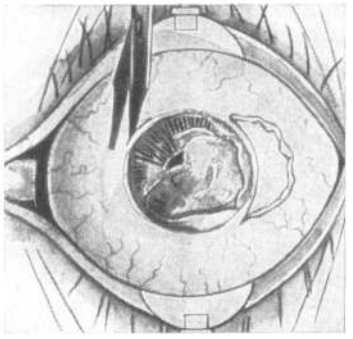


FIG. 39. Separation of the conjunctiva at the limbus for the fixation of the ribbon-shaped transplant by the scleral flaps.

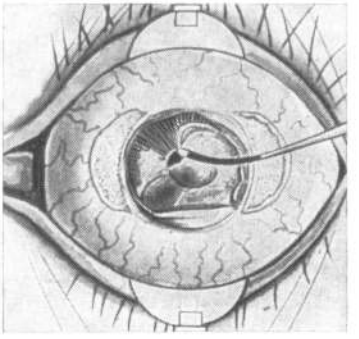


FIG. 40. Removing the epithelium and refreshing the surface of the ulcer.

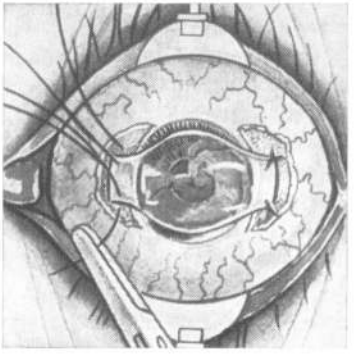


FIG. 41. Applying the absorbable sutures through the scleral flaps and the anterior layers of the sclera.

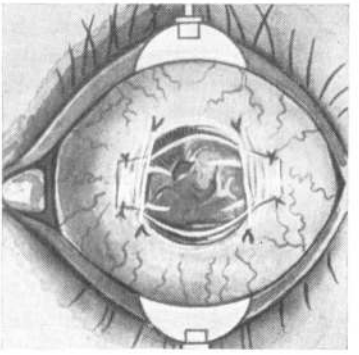


FIG. 42. The conjunctiva covers the scleral flaps of the graft.

rated from the cornea with a scraper or a round knife approximately in the posterior third of the cornea or sclera. The cornea may also be separated with a spatula. In tailoring a ribbon-shaped transplant two curved non-perforating incisions are made with a scraper in the cornea and sclera to form the scleral flaps. If the diameter of the donor cornea is the same as that of the cornea of the eye ope-

rated on, and the latter is not greatly changed, the transplant may be formed without scleral flaps.

3. Separation of the conjunctiva at the limbus in line with the sutures applied to the transplant (Fig. 39) and removal of the epithelium from the surface of the affected cornea with a scraper (Fig. 40).

4. Fixation of the transplant to the episclera at the limbus by means of absorbable sutures. If the transplant has scleral flaps two sutures are applied to the corner of each flap and passed through the sclera in such a way that the graft takes the shape of the cornea of the eye operated on and, at the same time, is drawn tight (Fig. 41); then one or two sutures are applied to the conjunctiva so that the scleral areas would be completely covered with it (Fig. 42). A binocular bandage is applied for two or three days.

Superficial therapeutic keratoplasty may be used very widely, since it is an absolutely safe operation. Since the corneal tissue of the affected eye is not cut away in this type of keratoplasty, then even if the transplant is rejected the condition of the cornea remains unchanged. In such cases it is necessary to repeat the same operation immediately.

The grafted transplant most often begins to resorb on the third to fourth week. Its taking occurs only in cases when therapeutic transplantation was undertaken in fusion or extensive deep ulcer of the cornea.

The total resorption of the graft is usually awaited. If the scleral flaps under the conjunctiva fail to resorb for a long time, they may be removed. During the operation it is necessary to cover the scleral flaps very carefully with the conjunctiva, otherwise resorption of the transplant can begin from the sclera, which is less desirable. The therapeutic effect of the transplant is apparent very quickly. Pain ceases immediately, inflammation diminishes and the hypopyon resorbs.

According to our observations, therapeutic keratoplasty, if applied in good time, prevents perforation of the cornea.

To obtain that in fusion and ulceration of the cornea after the burn, repeated keratoplasty has sometimes to be performed.

Almost in all cases of severe and particularly severe eye burns perforation of the cornea can be prevented and the eyeball kept intact by timely therapeutic, especially therapeutic superficial, keratoplasty (before perforation sets in).

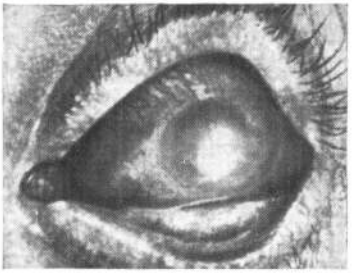


FIG. 43. Patient R. A deep persisting corneal infiltrate in the left eye after a lime burn.

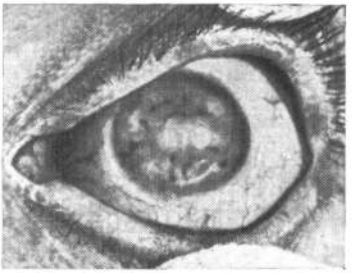


FIG. 44. Patient R. The same eye two months after therapeutic superficial lamellar keratoplasty. Limited opacification of the cornea on the site of the infiltrate.

Later on it is far from always possible, of course, to restore vision in such patients due to the severity of the affection.

We became convinced that therapeutic keratoplasty is also the best possible measure in deep corneal infiltrates.

Therapeutic superficial keratoplasty is likewise indicated in persisting erosions and ulcers.

Here are the data from the case history.

R. was admitted to the Institute with deep, persisting infiltrate of the cornea of left eye and acute inflammation developed after a lime burn (Fig. 43). The contralateral eye was healthy. Therapeutic superficial lamellar keratoplasty was carried out. In two months the transplant resorbed completely, inflammation ended and limited opacity of the cornea remained in place of the infiltrate (Fig. 44).

In occasional cases with extremely severe damage to the cornea attended with cicatrization of the skin of the eyelids and the formation of symblepharon, and, to top it all, the cornea still cannot be fully closed by the eyelids, which threatens inevitable perforation, an attempt may be made to transplant a flap of oral mucosa onto all the anterior surface of the eyeball. Remnants of the epithelium are scraped off the cornea beforehand, and a rectangular graft of the patient's mucosa with rounded corners is applied to the surface of the eye and stitched to the anterior layers of the sclera so that it might be stretched tightly. If the graft takes, it sufficiently prevents corneal perforation. It does not always take, however, in which case it becomes neces-

sary to cut the adhesions between the eyelids and eyeball, refresh the free margins of the eyelids, and perform blepharorrhaphy with sutures on two needles as indicated in Chapter VII in the description of the second stage of symblepharon removal. Further, in six to eight months, when the inflammatory phenomena subside, the palpebral fissure can be opened, the symblepharon removed and optic keratoplasty then carried out.

We performed therapeutic lamellar corneal transplantation, including superficial lamellar type, on many patients with eye burns, and found it to be invariably valuable. It is absolutely safe and can therefore be widely recommended in such symptoms, complicating the burn process, as fusion and ulceration of the cornea, non-healing erosions, hypopyon, deep corneal infiltrates and sharp inflammatory phenomena in the presence of changes in the cornea.

### EARLY PLASTIC SURGERY OF THE EYELIDS

In severe eye burns, especially in acid and thermal burns, there is often extensive involvement of the skin of the eyelids and surrounding areas, subsequently leading to the formation of cicatrices, ectropion and gaping of the palpebral fissure. Even if the cornea is in a good condition, deep lesions of the skin always cause apprehension for the state of the eye.

In the first weeks, when the skin is covered with a scab, ophthalmologists usually take a temporizing position. In many instances, however, such tactics are erroneous, because the shedding of the scab is followed immediately by rapid cicatrization of the skin leading to all the changes noted above. To avoid this, it is necessary, no later than the second week, to cover the granulating surfaces of the affected skin areas of the eyelids with epidermis by Thiersch's method or with very thin skin flaps. The thin flaps or the epidermal layers are cut off with a dermatome or a scalpel and applied to the granulating surface of the damaged areas. If the skin of the eyelids and face is burnt over an extensive area, a pressure bandage is not applied; the surface of the flaps and the surrounding skin may be smeared with an indifferent ointment and the flaps covered with pieces of gauze of the needed size, or, in very severe extensive burns, the face may be covered entirely by a net.

The transplanted flaps do not always take, but if they do, cicatrization of the skin and all sequelae are prevented.

When the patient is admitted with cicatrization of the skin, shortening of the eyelids, and lagophthalmos, it is necessary to perform plastic surgery of the eyelids immediately to avoid complications in the cornea due to gaping of the palpebral fissure. In such cases skin plastics by the common method is most often performed as it is described in Chapter VII.

Our observations have shown the unquestionable expediency of the early plastics of the eyelids in the very first weeks after the burn to prevent the development of severe cicatricial changes.

The data discussed in this chapter provide vivid illustration that ophthalmologists possess active methods and means for combating impending severe complications which can result in loss of the eye. Although these methods are not always effective, active treatment, individualized at every stage of the burn process, may nonetheless preserve the eye even in very severe burns and thus provide an opportunity for subsequent optic operations.

CHAPTER VII

# Surgical Treatment of Cicatricial Changes of the Eyelids and Conjunctiva in Burn Sequelae

Quite often cicatricial changes develop in the skin of the eyelids and conjunctiva after severe chemical and thermal burns. This leads to the entropion and ectropion of the eyelids, cicatricial deficiency of the conjunctival sac, gaping of the palpebral fissure and formation of adhesions between the eyeball and the eyelids (symblepharons and ankyloblepharons).

This is attended in most cases by the involvement of the cornea, as a result of which stable opacities and leucomas of the cornea form.

In this chapter we shall deal with the surgical methods for treating cicatricial changes in the eyelids and conjunctiva developing as sequelae of eye burns. For the main part it describes methods elaborated or improved at the Filatov Institute of Eye Diseases and Tissue Therapy.

The vast amount of material and long follow-up periods provided grounds for reliable conclusions on the results and their effectiveness.

## CORRECTION OF THE ENTROPION OF THE EYELIDS

Sapezhko's operation usually suffices to correct a small entropion caused by cicatrices of the free margin and the conjunctiva of the eyelid. With regard to its techniques, it should be pointed out that a thick prismatic graft with the submucosa is preferable for transplantation into the intermarginal space in these types of entropion. Transplantation of such wedge-like grafts has a better effect than that of thin grafts in regard to correcting entropion.

After infiltration anaesthesia an incision is made along

the entire eyelid in the intermarginal space to a depth of 8 to 10 mm. When the margin of the eyelid is scarred, two additional incisions can be made through the full thickness of the anterior plate of the eyelid at the lateral and medial edges to a depth of 5 to 6 mm. A prismatic graft 2.5 to 3.0 cm long and 4 to 5 mm wide, with tapering ends, is tailored from the mucous membrane of the lip or cheek (where the mucosa is thicker). The edges of the intermarginal incision are then drawn widely apart, bleeding is carefully arrested and the graft is fitted between the edges of the wound. It is necessary to wait for a certain length of time and abundantly cover the margin of the eyelid with sterile vaseline or sulphacyl ointment. Then a gauze-cotton ball smeared with ointment is applied and a binocular bandage is placed.

If the graft fits badly one thin suture (silk or absorbable) should be placed on each, lateral and medial, edge of the wound with a corneal needle. The bandage is changed for the first time on the third postoperative day.

Such wedge grafts take well as a rule. The intermarginal space can be wide in the first postoperative days, but then it gradually narrows. In marked cicatricial entropion of both eyelids resulting from a burn or an operation for correcting a symblepharon the principal effective method is an operation which we proposed for lengthening the posterior plate of the eyelid with transplantation of a mucosal graft and blepharorrhaphy, the techniques of which are described below.

## TRANSPLANTATION OF FREE SKIN GRAFTS IN ECTROPION OF THE EYELIDS

Severe burns often leave cicatrices in the skin of the eyelids leading to their shortening and eversion, which are corrected by plastic surgery with transplantation of the skin.

Many authors have described various methods of such operations and different techniques for fixation of the skin grafts. We shall discuss the operative techniques which have been used at the Institute for many years and fully justified itself.

The stages of the operation for correcting cicatricial shortening of the skin and ectropion of the eyelids are as follows.

1. Preparation of the operative field.

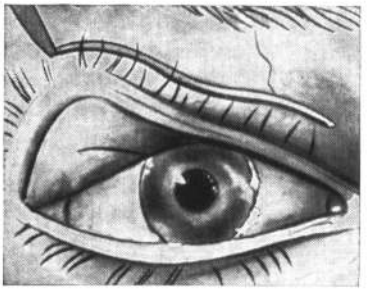


FIG. 45. Incision of the skin made 5 or 6 mm from the margin of the eyelid.

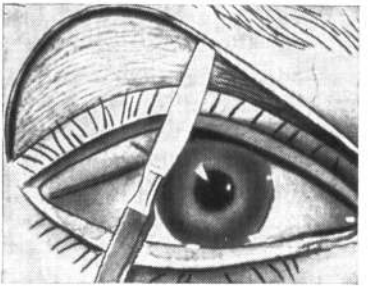


FIG. 46. Separating the skin.

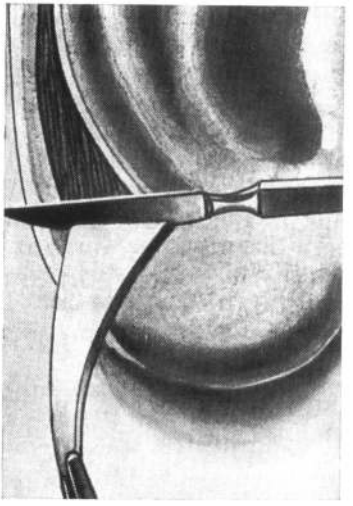


FIG. 47. Taking a skin graft from the posterior surface of the ear.

2. Incision of the skin parallel to, and at a distance of 5 to 6 mm from the free margin of the eyelid (Fig. 45), usually along its entire length. A thin skin layer is then separated without the underlying tissue, which is most important, beginning from the line of incision and advancing over as large an area as possible, to set apart the scars

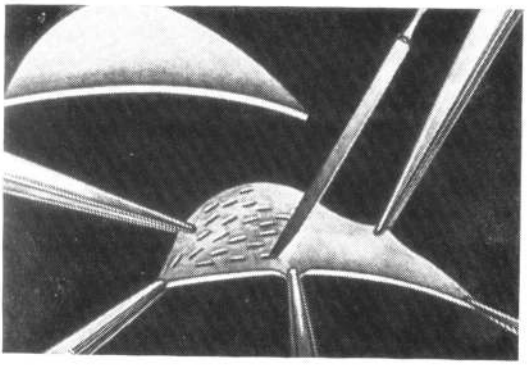


FIG. 48. Making perforating incisions with Graefe's knife in the skin graft.

and adhesions as much as possible (Fig. 46). With correct separation a large skin defect is formed. If any contracting cicatrices are left in the deeper tissues after separating the skin, these tissues should be separated with thin plates and incisions made in them so that they may be stretched and drawn apart. Excision of the cicatrices usually has no effect because adhesions and cicatrices form anew.

3. Tailoring the skin grafts. It is best to take skin from the posterior surface of the pinna or the skin behind the ear for covering the defect (Fig. 47). For this purpose we now use a dermatome of Soviet make employed in surgery (Gushcha, 1967). Grafts taken from these areas closely resemble the skin of the eyelids in thickness and colour and in just a few months after transplantation become hardly noticeable. If the skin cannot be removed from these sites because of scars, it is best to take it from the inner surface of the arm. It is most convenient to cover the wound surface of the pinna with a flap of autoclaved preserved skin which improves the healing of the defect (Legeza, 1962).

The borders of the flap are traced with a scalped and the skin is separated without the subcutaneous tissue. We always use perforated grafts. For this purpose the flap is stretched with thumb forceps and numerous perforating incisions 1.5 to 2.0 mm long are made with Graefe's knife next to one another in checkered order (Fig. 48).

4. The skin flap is secured by two methods.

**1. Fixation with sutures and stent.** An accurate impression is taken from the skin defect in the eyelid with dental Stent's mass 0,7 or 0.8 cm thick. The skin graft is applied to the surface of the defect and sutured with silk (Fig. 49). After all the sutures have been applied, the stent is put over the flap, the sutures are joined into bundles of three-four threads and tied over the stent (Fig. 50).

Stent is very convenient for use, because it exerts uniform pressure on the skin graft, thus practically preventing necrosis and formation of haematomas under the flap, and displacement of the graft.

The surface of the stent is powdered with sulphacyl (Sebizon, sulphacetamidum natricum) and a binocular bandage applied.

**2. Pasting the flap on with Cyacrine.** Cyacrine is a glue which has been widely used in recent times at the Institute in skin plastics (Gushcha, 1967). After careful arrest of bleeding the borders of the perforated graft and the edges of the defect are grasped with forceps and smeared with Cyacrine. Gauze napkins are placed on the surface of the graft like tile and a binocular bandage is applied.

With the skin separated as far as possible and a good bed provided for the transplanted flap, the results of the operation are usually favourable. In deficiency of eyelids such an operation may, in future, be repeated.

Given here are photographs showing the result of plastic surgery involving transplantation of free skin grafts in patient G. with total bilateral ectropion of both eyelids after a thermal burn (Fig. 51). After the operation the eyelids were repaired (Fig. 52).

Transplantation of free skin grafts in ectropions, even when they are considerable, has great advantages over other methods because the mobility of the eyelid is retained.

Some authors widely employ Filatov's tube flap graft or microtube flap in sharply pronounced cicatricial eversion of the eyelids (Zaikova, 1965, 1969, and others).

From vast experience in plastic surgery in cicatricial deficiency of the eyelids we became convinced of the advantages of transplanting free skin grafts in such cases.

Filatov's tube flap is absolutely irreplaceable in complete loss of the eyelids, when all other methods are of no value. Eyelids created by means of a tube flap

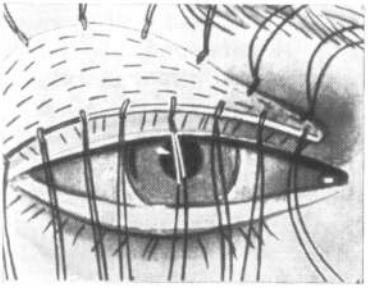


FIG. 49. The sutures are tied, leaving long loose ends.

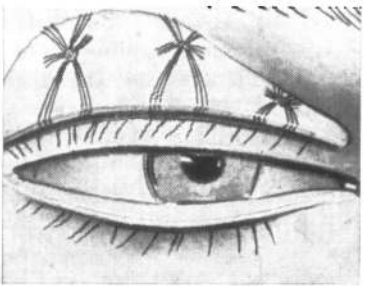


FIG. 50. The suture ends are joined in bundles and tied over the stent.

FIG. 51. Patient G. A full bilateral ectropion of both eyelids after a thermal burn.

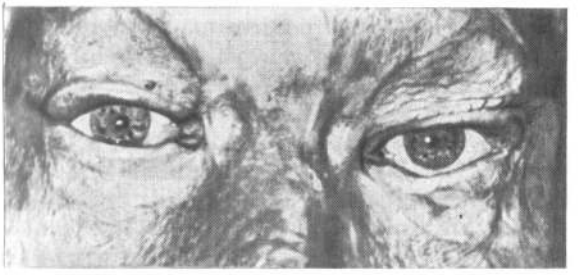


FIG. 52. Patient G. After plastic operations with transplantation of free skin grafts (the grafts were secured by sutures).

graft are always immobile and thickened. When the eye is absolutely bared and has no eyelids, that can, of course, be ignored to save it. In those cases, when the mucous membrane of the eyelid is preserved and the cicatrices, though considerable, involve the skin alone, preference should be given to transplantation of free skin grafts.

## RESTORATION OF FREE MARGIN OF THE EYELID, THE CANTHUS AND FORMATION OF EYELASHES

Restoration of a free margin of the eyelid is not an easy task. The conjunctiva, which is always covered with a crust, sometimes grows over the free margin damaged as a result of a burn. When the crust crumbles away the surface of the free margin can bleed. In such cases a prismatic cutaneous-cartilaginous graft taken from the pinna, and with the skin covering the base of the prism, may be transplanted into the split intermarginal space. The graft is usually tailored from the posterior surface of the ear in the thickest and hardest part. After anaesthesia has been produced, a deep 3.0 to 3.5 cm long incision is made through the skin and cartilage with a scalpel held almost perpendicular to the surface of the ear (care should be taken that the cut is not perforating). A second cut is then made parallel to it at a distance of 2.5 to 3.0 mm, with the blade of the scalpel held at an angle of 40 to 45° to give the graft the shape of a prism. Both ends of the graft are shaped as wedges. A 5.0 or 6.0 mm deep incision is made intermarginally along the whole length of the eyelid, and the cutaneous-cartilaginous graft is inserted into it. The ends of the graft are fastened to the cartilage of the eyelid of the eye operated on with sutures, so that it is tightly stretched along the whole length of the eyelid. Absorbable sutures are very convenient for this purpose.

Several such sutures may be applied in addition on both sides of the graft. A binocular bandage is applied for three or four days. If the sutures on both ends of the graft had been applied securely it takes without complications.

As a result of this operation a new free margin of the eyelid covered with epidermis is formed. We tried to correct a small deficiency of the eyelids by means of such a repeated manipulation. It should be emphasized that this is possible

only when the gap between the eyelids does not exceed 1 mm.

Sometimes, after several plastic operations, the eyelids become droopy and flabby. This happens when the cartilage of the eyelid is damaged or destroyed during previous plastic operations, in which case the eyelid consists only of skin and soft tissues. In these cases a thin 2.5×1 cm plate of the ear cartilage may be transplanted into the intermarginal space.

The outer and inner canthi of the palpebral fissure can be damaged as a result of a burn. The disturbance of their position and shape causes a noticeable asymmetry. Correction of the inner canthus of the eye is a very trying task and the operation must be meticulously planned for each individual.

It is easier to cope with distortion of the outer canthus. An intermarginal incision is made corresponding to the canthus to a depth of 1.5 or 2.0 cm, or the tissues in the region of the canthus are split if the free margin of the eyelid is destroyed. A thin rectangular plate measuring 2.0×2.0 cm is tailored from the ear cartilage.

A triangle is cut out of the cartilaginous plate along the midline with the apex reaching the centre of the plate. The base of the triangle varies from two to three millimetres depending on the shape of the patient's palpebral fissure. The plate is inserted between the split tissues in the canthus. Sutures are passed through the eyelid and plate for fixation. Absorbable sutures are also preferable in this case. The cartilaginous base gives the outer canthus of the palpebral fissure a good shape.

Let us now discuss the techniques of transplanting eyelashes in cases when they are lost. There are various methods, but we shall not engage in describing them here.

We shall dwell on our own experience in this field. During an operation for symblepharons and ankyloblepharons in the eyes of patients who had suffered severe chemical and thermal burns, it was sometimes necessary to improve the cosmetic appearance of the eye, especially when the other eye was healthy. With this purpose in view we grafted a skin band taken from the patient's eyebrow along the eyelid margin. The technique of this operation, which we have used for years, is described by Legeza (1965). It is indicated when the eyebrows are sufficiently thick and dark,

because only this can provide for success. Such an operation can only be performed on the upper eyelid. The technique is easy and similar to that of Sapezhko's operation, but there are certain distinctive features in excising the skin band and making the incision along the margin of the eyelid. When cutting the skin graft from the eyelid, attention should be paid to the direction in which the hairs grow, since they grow slantwise. For that reason the skin should be cut with a scalpel at an angle to avoid severing the hairs from their bulbs, otherwise the operation will prove unsuccessful. Two 3.0-cm-long incisions are made, the first approximately along the middle of the eyebrow, the second 2.0-2.5 mm parallel to it. With the skin graft removed, sutures are applied to the edges of the wound. An incision 3.0-3.5 mm deep is made along the whole eyelid 1.0 mm above its anterior margin and the band of skin from the eyebrow is inserted into the slit. The skin graft should be fitted in such a way that the hairs would be directed upward. The graft is tightly fastened to the edges of the eyelid with absorbable or very fine silk sutures, first in the corners of the wound, and then along its length. At first the transplanted eyelashes drop out, but then, if the graft had been tailored correctly, and the hair bulbs had not been damaged, they grow anew.

The operation performed under the conditions described above may have a favourable cosmetic effect.

## SURGICAL TREATMENT OF EXTENSIVE SYMBLEPHARONS IN SEQUELAE OF SEVERE EYE BURNS

In severe chemical and thermal eye burns adhesions may form between the tissues of the eyeball and the eyelids, and between the free margin of both eyes. The length and depth of these adhesions vary from small ones to total accretion of the eyelids with the tissues of the anterior part of the eye. Solitary adhesions usually do not require removal unless they restrict the mobility of the eyeball. Extensive and total symblepharons always call for surgery to remove the adhesions, otherwise subsequent optic operations would be impossible.

Not very long ago the correction of extensive, and especially total adhesions between the eyelids and the eye-

ball was almost impossible. The existing methods for correcting symblepharons were not successful and could be used only in cases with small adhesions. Operations suggested for correcting extensive symblepharons had a number of disadvantages or could only be carried out on the lower eyelid (Pravosud, 1904).

In manuals and atlases on ophthalmic surgery (Kolen, 1950; Kurlov, 1955; Csapody, 1956; Arruga, 1962; Callahan, 1950) various plastic operations in localized symblepharons are described, but there is no information on any effective method for correcting extensive and total adhesions between the eyelids and the conjunctiva of the eyeball. We also could not find such information in current articles published in magazines both in the Soviet Union and abroad.

It is common knowledge that operations for correcting symblepharon involve transplantation of mucosal flaps taken from the patient's mouth or, more rarely, from other tissues, onto the wound surface of the sclera and eyelid formed after the adhesion had been divided.

Alberth (1968) suggests covering the wound surface of the sclera and iris with corneas, which is very difficult as regards material and the technique in cases with extensive and total symblepharons. It should be stressed that transplantation of skin, even in the form of thin grafts, is absolutely not indicated (though some authors do it) if it is expected to perform optic keratoplasty in the future.

Legeza (1962, 1970) studied in experiments and in the clinic the possibility of using homotransplantation of oral mucosa taken from a cadaver and preserved by various methods, and the effectiveness of the operation.

From numerous observations he concluded that the best method of preservation was that suggested by Belyakov, and elaborated clear-cut indications for homotransplantation of the mucous membrane in plastic operations for extensive symblepharons.

For several years we developed and tested in the clinic a method for surgical correction of extensive and total symblepharons occurring after burns and resulting from other causes, which proved to be very effective (Puchkovskaya, 1951, 1960).

It consists of two stages, the first one involving correction of the symblepharon and transplantation of the lip mucosa and its fixation with episcleral sutures.

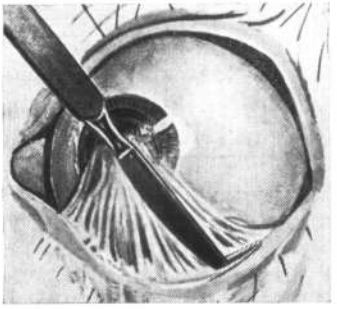


FIG. 53. Cutting the adhesions between the eyelids and the eyeball.

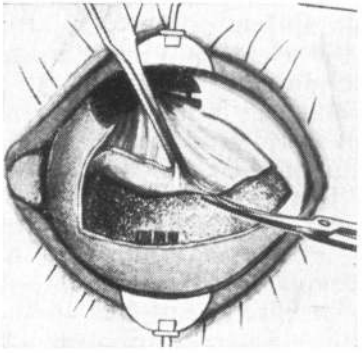


FIG. 54. Separating the cicatricial tissue.

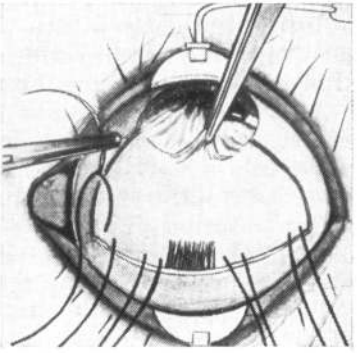


FIG. 55. Applying episcleral sutures.

The operative field is prepared and **the adhesions between the eyelids and the eyeball are then cut** with a scalpel and scissors (Fig. 53). The cicatricial tissue is excised (Fig. 54) but not to the sclera, otherwise circulation in the eye may be greatly disturbed.

**At the places where the episcleral sutures had been applied** a meridional incision is made in Tenon's capsule to the sclera along the sides of the straight muscles. Silk sutures are passed through the episclera and anterior scleral layers with a thin cutting needle, but a round needle for corneal sutures can also be used. The sutures are applied

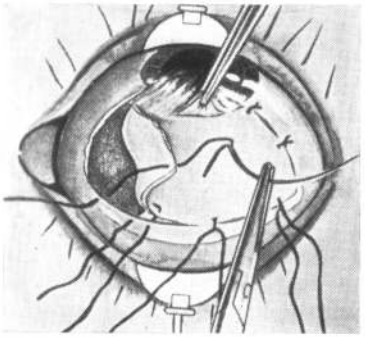


FIG. 56. Fixation of a mucosal graft with episcleral sutures.

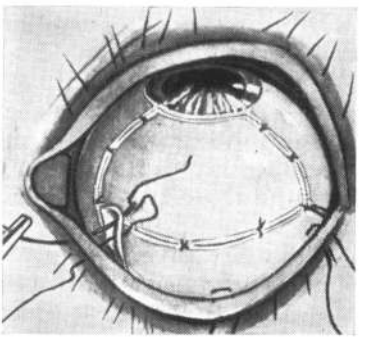


FIG. 57. Stitching the edge of the graft to the free margin of the eyelid with mattress sutures.

at a distance of 12 to 13 mm from the limbus (Fig. 55). In operations for total symblepharon of one (the lower) eyelid, for example, four episcleral sutures are sufficient: one applied close to the medial straight muscle, two along the sides of the inferior straight muscle and one close to the lateral straight muscle.

In an operation for total symblepharon of both eyelids, eight episcleral sutures are applied, two sutures on the sides of each straight muscle.

**A thin layer of the lip mucosa is removed.** An obligatory condition is the injection of a considerable amount of an 0.5 or 0.25 per cent procaine solution sufficient to make the lip compact. Sutures are not applied after removing the mucosa; gauze napkins are put over the defect for two or three hours. Before it is fitted to the eye, the mucosal graft is put into a sterile Petri dish with a small amount of physiological saline in it.

For **fixation of the mucosa** on the eyeball and posterior surface of the eyelids one of the grafts is fitted over the eyeball surface devoid of the conjunctiva and secured with episcleral sutures, applied beforehand (the threads are not cut away after that, because the mucosal flap covering the posterior surface of the eyelid will be fastened to them later). Additional sutures are placed at the limbus along the sides of the graft, so that the mucosa would fit closely and without folds to the sclera (Fig. 56).

In correction of a symblepharon the cicatricial tissues co vering the cornea should not be fully excised.

Another mucosal graft of the required size is fitted over the posterior wound surface of the eyelid and secured deep in the fornix with the same episcleral sutures with which the mucosa covering the eyeball had been anchored. After that the threads are cut off, leaving ends of at least 1 cm long.

The other edge of the graft is stitched to the free margin of the eyelid with mattress sutures (Fig. 57).

In operation performed for symblepharon of both eyelids a mucosal graft is secured to the other eyelid in the same manner. In some patients with extensive symblepharon and drastic shortening of the fornices, but with incomplete adhesion between the eyelid and the eyeball, it proves feasible to close the wound surface on the eyelid with the conjunctiva of the eyeball and eyelid. For that purpose the conjunctiva in the region of the symblepharon is cut at the limbus, separated up to the free margin of the eyelid and fitted over the posterior surface of the eyelid. One to three buried sutures are passed through the edges of the conjunctiva and the eyelid according to the depth of the fornix, which are brought out through the skin and removed in two or three days. Their purpose is to keep the conjunctiva in the required position in the first postoperative days. They are removed early so that the scars might not form along them. A thin graft of the lip mucosa is sutured to the wound surface of the sclera with episcleral sutures.

When the operation is over the mucosa is powdered with streptocide (sulphanilamide, streptamine, proseptine). A binocular bandage is applied.

As a result of this operation sufficiently deep fornices are restored.

In cases of symblepharon involving one third or two thirds of the eyelid's surface, one such operation usually produces the needed effect; the fornix is restored, and correct position of the eyelid and full closure of the palpebral fissure are obtained. Sometimes a small entropion remains, which is corrected by Sapezhko's operation.

If the operation was performed for correcting a symblepharon in total adhesion of one, and particularly of both eyelids, then cicatricial changes develop eight to twelve days afterward in the mucous membrane of the posterior

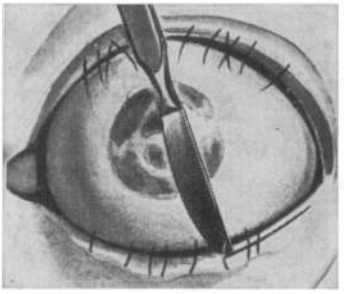


FIG. 58. Splitting the margin of the eyelid into anterior and posterior plates.

surface of the eyelids with cicatricial entropion and non-closure of the palpebral fissure. In such cases a second operation is necessary in three-to-four weeks.

The second stage consists in an operation for correcting cicatricial deficiency and entropion of the eyelids (lengthening of the posterior plates of the eyelids with transplantation of the lip mucosa and stitching of the eyelids).

After preparing the operating field an incision is made along the margin of the eyelids to **split** them into anterior (skin, muscles, cartilage) and posterior (mucous membrane) plates (Fig. 58 and 59).

**Collecting the mucous membrane.** A graft of the lip mucous membrane of the needed size is prepared by the method described above.

**Suturing the mucosal graft.** The graft of the mucosa is placed with the epithelial surface to the eyeball, and sutured to the edge of the posterior plate of the upper and lower eyelids with fine catgut or absorbable sutures (Fig. 60). The mucosal graft, after it has been sutured, should be stretched evenly, but not too tightly between the posterior plates of the upper and lower eyelids. Sutures are not applied at the lateral and medial parts of the palpebral fissure leaving small unstitched areas through which tears and secretions may flow freely from the conjunctival sac.

After that **anchoring sutures** are applied and the eyelids are sewed together. The margins of both eyelids are refreshed (Fig. 61) for which purpose a thin layer of tissue along the whole length of the intermarginal space is cut away

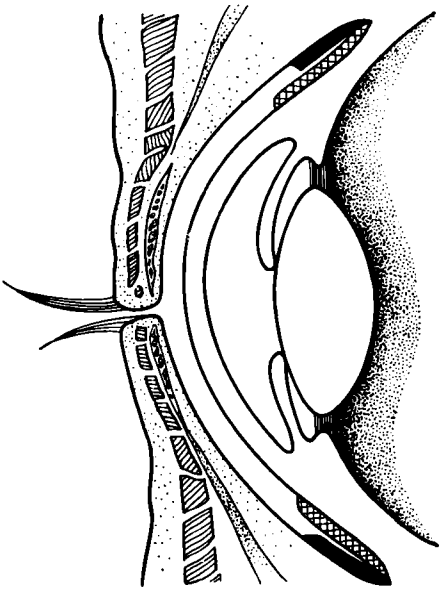


FIG. 59. A sagittal cross-section of the eyelids and the anterior part of the eye. After the eyelids are split the posterior plates (mucous membrane) of both eyelids move back to the fornices. The eyelids are now in a normal position.

The line formed by the closed eyelids is traced on the mucosal graft with a needle dipped in brilliant green. At a distance of 1.5 to 2.0 mm above and below this line one or two silk sutures on two needles are passed through the full thickness of the mucous membrane. Then both ends of each suture are brought out through the skin of the respective eyelid. The sutures are left untied. Eight to ten sutures are applied to the margins of the eyelid. They are passed first through the margin of one eyelid, and then through the margin of the other. The needle is inserted at the posterior edge of the free margin of the eyelid and brought out through the skin at the base of the eyelashes (Fig. 62). The sutures are tied with a surgical knot. Openings for the escape of tears and discharge should be left in the outer and inner canthi. After that the anchoring sutures are tied. A binocular bandage is applied.

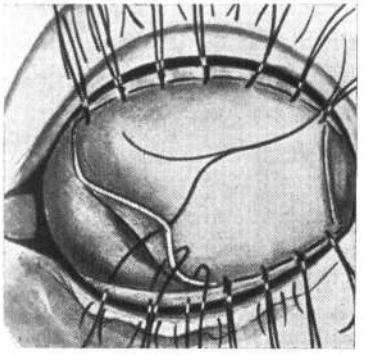


FIG. 60. The mucosal graft is secured by catgut sutures to the edge of the posterior plates of the mucous membrane of both eyelids.

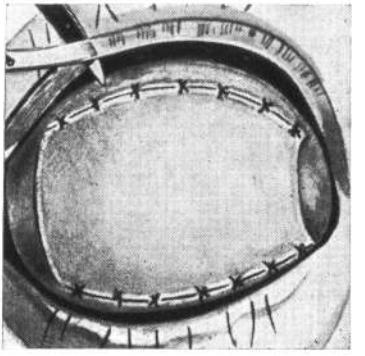


FIG. 61. Cutting away a fine layer of tissue in the region of the intermarginal space.

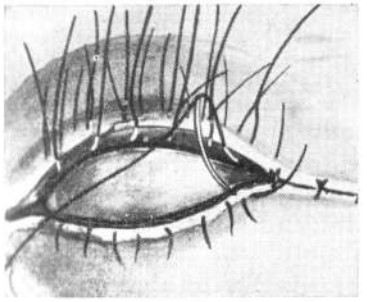


FIG. 62. Applying sutures to the margins of the eyelids.

In considerable damage to the skin and free margins of the eyelid, i.e. in traumatic shortening of the eyelids, simultaneously with an operation for lengthening the posterior plates (after the eyelids have been stitched together) we perform free transplantation of the skin to one or both eyelids, the techniques of which are described above.

The palpebral fissure is opened in three or four months after the operation for lengthening the posterior plates and sewing the eyelids together.

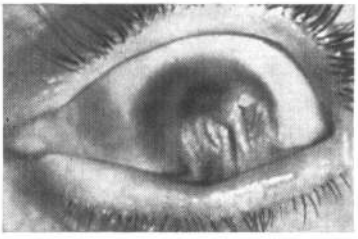


FIG. 63. Patient K. Partial symblepharon of the lower eyelid.

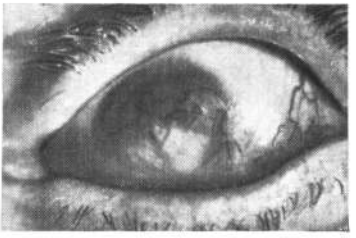


FIG. 64. Patient K. The same eye after removal of the partial symblepharon.

FIG. 65. Patient K-o. Extensive symblepharon of both eyelids, partial ankyloblepharon.

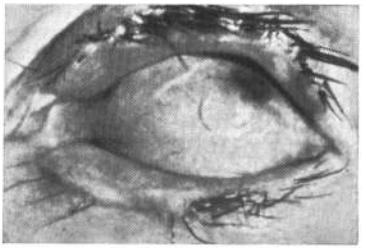


FIG. 66. Patient K-o. The same eye after two stages of surgical removal of adhesions.

After infiltration anaesthesia, a grooved probe is inserted through the unsewn parts of the eyelids in the outer and inner canthi. The tissues are then cut along the line of the sewn eyelids with straight scissors or a scalpel held before the probe (the mucosal membrane, which has been transplanted during the previous operation and has grown onto the posterior surface of the eyelids, is also cut). Bleeding is arrested. Streptocide (sulphanilamide) is abundantly applied between the wound surfaces of the upper and lower eyelids and a monocular bandage is applied. Thus, our method for surgical treatment of extensive and total symblepharons consists in performing one or two basic operations depending on the initial state of the eye operated on.

At present the Institute has at its disposal the results

of observations over more than a thousand patients with sequelae of chemical and thermal burns who were operated on for symblepharon by using our method.

The following are illustrations showing the effectiveness of surgical treatment of symblepharons of various extent.

Male patient K. Diagnosis: partial symblepharon of the lower eyelid after an acid burn (Fig. 63). An operation for correcting the symblepharon has been performed (Fig. 64).

Male patient K-o. Diagnosis: extensive symblepharon of both eyelids, partial ankyloblepharon after a lime burn (Fig. 65). Two stages of surgical correction of the symblepharon have been performed. The eye is free of adhesions (Fig. 66).

According to our data (1951, 1955) and to those of Legeza (1956, 1965, 1970), who studied the efficacy of the method, successful results were obtained in 96 to 97 per cent of the patients operated on. Successful treatment was evaluated on the basis of the following criteria: (1) depth of the fornices; (2) correct position of the eyelids; (3) completeness in the closure of the palpebral fissure.

The operation was considered successful only when the depth of the fornices of the eye operated on was normal or almost normal, the position of the eyelids was correct and the closure of the palpebral fissure was complete.

The results obtained permit us to state that the problem of elimination of extensive and total adhesions between the eyelids and the eyeball, which has until recently been regarded as practically impossible, has now been solved.

## CORRECTION OF CICATRICIAL DEFICIENCY OF THE CONJUNCTIVAL CAVITY IN ANOPHTHALMOS

There is a big variety of operations for reconstruction of the conjunctival cavity in anophthalmos (Kolen, 1950; Kurlov, 1955; Callahan, 1950; Csapody, 1956; Zaikova, 1969). The existence of many proposals and modifications is an evidence of the complexity of these operations, difficulty of producing an effect and a certain degree of dissatisfaction with the results obtained.

In this section we describe our method for correcting cicatricial deficiency of the conjunctival cavity in the absence of the eyeball.

After the operation for correcting extensive and total symblepharons had been developed (Puchkovskaya, 1951),

we decided to utilize the principle of the second stage of correcting cicatricial deficiency of the eyelids and the non-closure of the palpebral fissure for restoring the conjunctival cavity in cases of its cicatricial deficiency and anophthalmos.

We began performing such operations in 1951 and became convinced that in cases of cicatricial deficiency of the conjunctival cavity it also produces good results. The operation is described by Getman (1962) and Tagibekov (1967, 1971), who introduced additional techniques and used the operation on a large number of patients.

At present more than 130 such operations have been performed at the Institute.

The operative techniques are as follows: after preparing the operative field **the conjunctiva of the eyelids is separated** from the underlying tissues and cut along the whole length of each eyelid 1.0 to 1.5 mm from the margin and then separated to the centre of the eyeball stump.

**The grafts are tailored** from the mucous membrane. For this purpose the borders of the graft, which should be as large as possible (3.0×4.0 cm), are marked with a scalpel on the posterior surface of the upper and lower lips. The mucosa is then separated with a scalpel. Any areas of submucosal tissue remaining on it are cut away.

**Suturing the mucosal grafts.** The grafts are usually somewhat curved in shape. They are applied with the epithelium face down and the convex side facing the centre, and sutured with fine catgut to the lower and upper edges of the freed conjunctiva. The sutures applied to the upper edges of the graft are tightly tied and cut away. Those applied on the lower edges of the conjunctiva and the graft are drawn apart.

**The free margins of the eyelids are refreshed** in the same way as in the second stage of symblepharon correction.

**The application of the prosthesis.** An eye prosthesis or a special model of a prosthesis selected according to the size and shape is placed behind the mucosal grafts after which the sutures placed on the lower edge of the conjunctiva and the graft are tied. When necessary, auxiliary fine absorbable sutures are applied to join both mucosal grafts along the central line.

If the grafts are not drawn tight and lie loosely in relation to the prosthesis, two anchoring sutures should be

applied 2.0 mm above and another two 2.0 mm below a horizontal line drawn between the outer and inner canthi of the palpebral fissure. The sutures are placed with two needles inserted from the epithelial surface of the mucosa through the mucous membrane and the full thickness of the eyelid 2.0 mm above or below the free margin of the eyelid.

**Sewing the eyelids together.** The eyelids are sewed to each other with eight to ten sutures in the same manner as described in the second stage of the operation for symblepharons. They are powdered with streptocide at the end of the operation. The gauze surface of the ball is smeared with ointment. A binocular bandage is applied.

This operation is performed in deficiency of the conjunctival cavity resulting from injury or burn, if the eyeball has been enucleated at the previous stage of treatment. We do not perform enucleation in burn sequelae, because it is far easier to obtain the restoration of the fornices for wearing a thin-walled prosthesis when there is an eyeball, than in anophthalmos.

As a result of surgery in half of the patients the conjunctival sac was completely restored, and in one fourth of the patients considerable improvement was attained after additional operations permitting patients to wear prostheses. In 25 per cent of the patients the operation was not successful. It should again be stressed that this operation is indicated in cicatricial deficiency of the cavity and in anophthalmos. In total absence of the conjunctival cavity results are obtained only in occasional cases.

## PROSTHETICS AND COSMETIC CORRECTION

In cases when after correction of an extensive symblepharon, it is obvious that vision cannot be restored while the second eye can see, a good cosmetic effect is produced with a thin-walled prostheses (Puchkovskaya, 1951; Legeza, 1956). Due to synchronous movement of both eyes, a well-chosen thin-walled prosthesis may be taken for a genuine eye. For that reason we prefer not to enucleate an eye with a flattened anterior segment unless there are some special indications.

A thin-walled prosthesis, however, is not always indicated. In cases of a distended eye or considerable corneal

ectasia its use does not produce the desirable effect. An individual prosthesis is always required after an operation for correction of cicatricial deficiency of the conjunctival cavity in anophthalmos. In distinction to thin-walled prostheses, which are fitted to the eyeball, an ordinary prosthesis applied instead of the eyeball is easily noticeable as a rule.

In such cases, and sometimes with thin-walled prostheses for instance when the palpebral fissures differ in width, or one eye protrudes more than the other, cosmetic correction may be of great value (Pogoretsky, 1949; Tagibekov, 1971). With well-chosen optical glasses the appearance of a patient wearing a prosthesis may be quite natural.

* * *

The principles and methods of surgical treatment discussed in this chapter have been employed at our Institute over a considerable time on many patients (more than a thousand). As experience has shown, these operations are very effective and absolutely essential for many patients with grave sequelae of eye burns, which justifies our right to recommend them widely for use in ophthalmological practice.

CHAPTER VIII

# Optic Operations in Leucomas of Burn Aetiology

The basic optic operation in leucomas caused by burns (just as by any other factors) is transplantation of the cornea, although precisely vascularized leucomas of burn aetiology are least favourable for keratoplasty.

Even a very small improvement of vision may be of utmost importance and therefore, in partial leucomas, it is always important to clarify to what extent iridectomy or sphincterectomy will improve vision. It is necessary to test thoroughly visual acuity with a narrow pupil, a pupil dilated to a maximum and by the stenopeic method. Under all these conditions visual acuity must be tested without and with correction.

If with dilated pupil the vision is not increased and only increases when tested with a stenopeic device under these conditions, the expediency of iridectomy must be weighed, since the operation does not provide vision equivalent to that found by stenopeic examination.

When a slight dilation of the pupil produces an optical effect, it is necessary, if possible, to perform a partial coloboma, or sphincterectomy, because a total coloboma may cause unpleasant sensations on exposure. In iridectomy and sphincterectomy an incision should be made in the scleral part of the limbus, because, bearing in mind the presence of the leucomas every millimetre of the transparent cornea must be carefully saved. When there are posterior synechiae, the iris may be grasped at the pupillary border with a special blunt hook and carefully drawn out of the wound. Having taken hold of its edge with forceps, a piece of the iris or the pupillary border (in sphincterectomy) is cut away with iris-scissors, and then the iris is fitted back in place with a spatula. After smoothing out the iris, a fine

absorbable suture may be applied to the edges of the incision.

After burns, particularly with alkali, secondary glaucoma may develop in the affected eye. We performed operations of the Lagrange-Holth type and iridencleisis at the Institute, which gave favourable results in some of the patients. In such cases Klyutsevaya (1968) recommends an iridotasis elaborated by her (the folding of the iris into the suprachoroidal space) by means of which she succeeded in achieving favourable results in secondary glaucoma. In any event, if there are indications both for an optic and for an antiglaucoma operation, an attempt should be made to combine them into a single operation, if possible; for instance, to perform an iridectomy opposite the transparent corneal area, and strangulation of one of the coloboma pillars in the upper part of the limbus.

## EXTRACTION OF THE CATARACT

Although opacity of the lens is not a very frequent occurence after a burn (in ammonium burns cataract develops often and very early), an ophthalmologist, nonetheless, has also to tackle the operation for extracting a cataract in patients with partial leucomas of burn aetiology. Prior to the operation, the thickness of the lens is measured with ultrasonics, since it is essential to know this beforehand.

Ultrasonic echography helps ascertain the details in the condition of an eye with leucomas. Thus, the echogram in Fig. 67 shows that the anterior chamber and the lens in the examined eye are of normal thickness and that there are no significant changes in the posterior eye segment. The echogram of an eye with a leucoma in Fig. 68 shows thickening of the cornea; the anterior chamber and the lens are of the usual size, the posterior segment—with no changes of note. Fig. 69 shows an echogram of an eye with a leucoma demonstrating a single echo-signal from the lens, which testifies to the presence of a membranous cataract. The echo-signal immediately in front of the posterior wall of the eye is evidence of retinal detachment.

If there are no contra-indications, intracapsular extraction of the lens may be performed. In the presence of a leucoma the operation is somewhat more complicated.

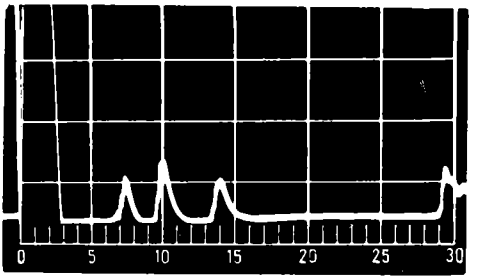



FIG. 67. The echogram of an eye with a leucoma. The cornea is of usual thickness. The anterior chamber is of normal depth and the lens is of normal thickness.

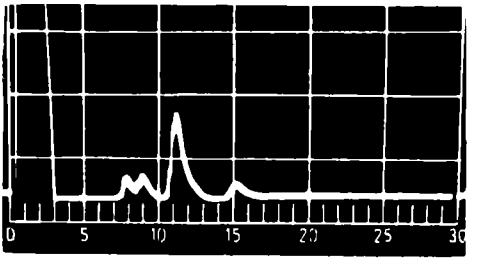



FIG. 68. The echogram of an eye with a leucoma showing thickening (the double-spur of the echo-signal) of the cornea. The anterior chamber, lens and posterior part of the eye have no abnormalities.

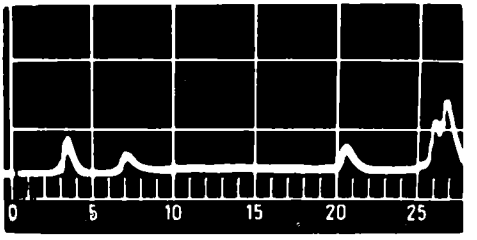



FIG. 69. The echogram of an eye with a leucoma. There is a single echo signal from the lens, pointing to the existence of a membranous cataract; the single echo signal before the posterior wall of the eye is evidence of retinal detachment.

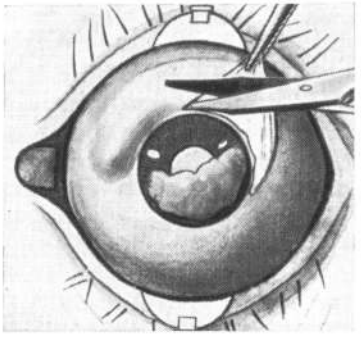


FIG. 70. Incision of the conjunctiva along the limbus in the top half and its separation.

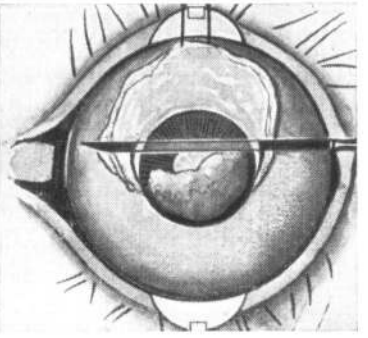


FIG. 71. An incision in the limbus made with Graefe's knife.

Over a period of several years, pondering over every moment in the techniques of cataract cryo-extraction and analysing every complication, we settled on a definite standard operation, which we find satisfactory in the main.

Let us dwell on certain moments of the cataract cryo-extraction techniques which we apply.

Much attention should be focussed at general pre-operative management of the patient, adopting an individual approach according to the peculiarities of the patient's organism. It is recommended to lower intra-ocular pressure in the eye just before it is operated on. If there are no contra-indications (high myopia, displacement of the lens, etc.) intra-ocular pressure may be lowered by massage of the eye.

After retrobulbar, infiltration and epibulbar anaesthesia the conjunctiva is separated. For several years now, we have been cutting the conjunctiva along the limbus (Fig. 70) to half of its circumference and then separating it toward the equator. In using absorbable sutures, this method has great advantages; the conjunctiva is not in the way during the operation because it is held back by the bridle suture applied to it after separation, whereas at the end of the operation it covers the corneoscleral sutures tightly, which improves the airtightness of the operative wound. Repeated surgery with separation of the conjunctiva at the limbus is quite possible, because the former heals in its customary

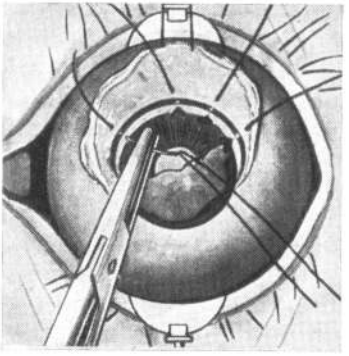


FIG. 72. The application of corneoscleral sutures to the limbus.

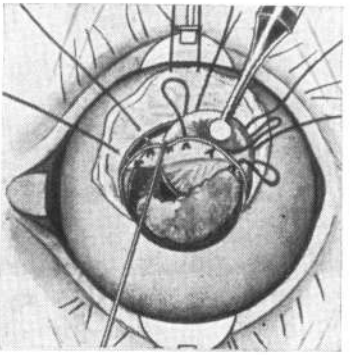


FIG. 73. The removal of the lens with a cryo-extractor.

bed. *Flieringʼs* ring is stitched to the sclera if there are grounds to presume that the crystalline lens may collapse. The incision in the scleral part of the limbus for half of its circumference is made with Graefe's knife (Fig. 71), and in a shallow chamber—with a scraper and scissors. When Graefe's knife is used, the incision usually also has to be enlarged with scissors.

A safeguarding suture with a knot on one end is passed through both edges of the incision (corneal and scleral) at 12 o'clock. A second suture with a knot on its end is placed next to it, but passed only through the corneal edge of the incision.

This is an anchoring suture by means of which the assistant draws back the cornea and holds it in the required position at the moment the lens is being extracted.

The advantage of the suture over the use of forceps for holding the cornea consists in the fact that at any given moment it can be released, whereas it takes some time to remove the forceps. To attain maximum efficiency of movement, the assistant should hold the suture at a distance of 4 to 5 cm from the eye. After that several corneoscleral absorbable sutures, also with a knot at one end, are applied. They are passed at the depth of the posterior third of the thickness of the corneal edge. Their number depends on the diameter of the cornea (Fig. 72).

Five to six sutures are usually enough to ensure adequate airtightness of the operative wound.

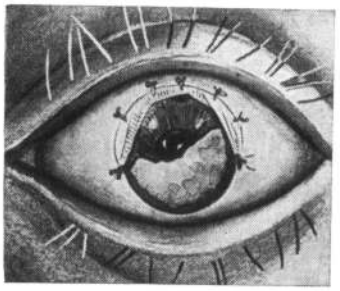


FIG. 74. The conjunctiva has been stretched over the area of the incision and the corneoscleral sutures are visible through it.

After that the sutures are drawn apart and basal iridectomy is performed. We always use two forceps for grasping the iris. At first the iris is grasped with fine curved anatomical forceps at 12 o'clock and pulled slightly forward so that its root is visible. Then its tissue is grasped with iris forceps at the root and cut away.

If the iris is immediately taken with the iris forceps at the root, the capsule of the lens may sometimes be damaged.

In operations performed on young patients retro-iridian injection of alpha-chymotrypsin (1:5000) is made through the basal coloboma on both sides of it; the preparation should be thoroughly washed out in two to three minutes. We irrigate the anterior chamber with Ringer-Locke or balanced solution because the incidence of postoperative descemetitis is less than with the use of physiological saline.

The crucial point of the operation is the extraction of the lens (Fig. 73). The assistant holds the bridle suture and pulls the cornea with the anchoring suture. The surgeon moves aside and holds the iris with a compact thin cotton rod moistened in physiological saline in one hand, extracting the lens with a cryo-extractor held in the other. The lens must be taken out very slowly. When most of the lens has been removed from the region of the pupil and there is no longer any danger of the iris being frozen

to the cryo-extractor, the cotton rod is taken away from the iris and may be used to help extract the lens.

As soon as the lens is out, the assistant immediately tightens the safeguarding silk suture with the knot at its end. The anchoring suture on the cornea is cut and removed. The iris is carefully smoothed out with a spatula to make the basal coloboma visible, and the sutures are tied; after that the safeguarding silk suture is removed, and, if necessary, replaced with absorbable sutures. A Ringer-Locke solution is injected into the anterior chamber. If the diameter of the pupil is 4 or 5 mm after the operation, we do not instill either miotics or mydriatics. If the pupil is narrow, atropine is instilled, with a wide pupil—pilocarpin. The bridle suture is removed. The conjunctiva is stretched by means of two episcleral sutures at the limbus, over the incision, and the sutures passed through the sclera (Fig. 74). Subsequently it returns to its place. A binocular bandage is applied. Using such operative techniques, we encountered practically no aggravations in removing complicated cataracts.

Patients require very scrupulous observation in the postoperative period, because changes leading to late complications may then develop. After cataract cryoextraction the patients should be placed under close daily observation of an ophthalmologist for no less than a month.

## KERATOPLASTY

As it was stated above, the main optic operation for sequelae of eye burns is corneal transplantation, since the cornea is most frequently damaged in a burn and leucomas form. They are poorly conducive to corneal transplantation. In most cases after severe eye burns there is considerable vascularization of the cornea, often with growth of cicatricial tissue over it. That is why the main operation in vascularized post-burn leucomas is lamellar rather than perforating transplantation of the cornea.

Some authors (Barkhash, 1947; Ilchenko, 1953; Bushmich, 1954; Nguyen Chong Nyan, 1964) cite various information on the efficacy of partial penetrating corneal transplantation in patients with leucomas formed after a burn.

Our numerous observations of corneal transplantation in patients with vascularized leucomas resulting from eye burns

revealed in all evidence that penetrating keratoplasty in such cases has no effect and is dangerous, because taking of the graft is often delayed, as a result of the lowered regenerative property of the tissues, the anterior chamber is not restored for a long time and anterior synechiae form with subsequent development of secondary glaucoma. These complications lead to opacity of the transplant, and sometimes to the loss of the visual function of the eye. We proved (Puchkovskaya, 1951, 1955, 1960) that lamellar corneal transplantation is the basic type of keratoplasty in leucomas of burn origin, with the aid of which vision may be restored even in very grave consequences of the burn.

It is common knowledge that this type of keratoplasty was proposed as far back as in 1840. Many ophthalmologists employed lamellar keratoplasty for optical purposes, but failed to produce the desired results because the transplanted cornea turned opaque.

In the thirties Filatov showed the importance of lamellar keratoplasty as a meliorative transplantation. He was the first to elaborate the operative techniques of total lamellar transplantation of the cornea (Filatov, 1937, 1945), and the operation was widely used at his Institute for meliorative purposes, i.e. to improve quality of the leucoma for future perforating keratoplasty.

In postwar years total lamellar corneal transplantation in our modification began to be first used at the Filatov Institute of Eye Diseases and Tissue Therapy for optic purposes in leucomas due to burns (Puchkovskaya, 1951, 1955).

To date, over three thousand of such operations have been performed at the Institute for optical, tectonic and meliorative purposes. Now optic lamellar keratoplasty is widely used by ophthalmologists in the Soviet Union (Petrunya, 1963; Kuksa, 1966; Gudkova, 1966; Porshnev, 1966, and others).

In postwar years optic lamellar keratoplasty began to be employed also in other countries. Operative techniques and results of lamellar keratoplasty are described in many articles and monographs dealing with transplantation of the cornea (Paufique *et al.*, 1948; Rougier, 1950; Paton, 1955; Rycroft, 1955; Castroviejo, 1968). It should be noted that with the exception of Alberth (1968), who cites data similar to ours, other authors performed lamellar kerato-

plasty mainly in degenerative and dystrophic changes in the cornea and in superficial leucomas of various aetiology.

The wealth of clinical observations conducted at the Institute of patients with leucomas developed after eye burns who were treated by optic lamellar keratoplasty, is unique in volume and permits authentic conclusions to be made with regard to the effectiveness of the operation and indications to it.

Three main types of optic lamellar keratoplasty may be distinguished according to the peculiarities of the techniques: (1) partial lamellar, (2) subtotal and total lamellar, (3) peripheral lamellar keratoplasty.

### PARTIAL LAMELLAR CORNEAL TRANSPLANTATION

This type of lamellar corneal transplantation as an optic operation is indicated in central superficial avascular corneal opacities, a condition rarely occurring after a burn. The diameter of the corneal graft in partial lamellar keratoplasty ranges from four to six millimetres. The essence of the operation consists in removing the opaque anterior corneal layers on an area with a diameter of 4 to 6 mm and their replacement by a corneal graft which comprises the anterior corneal layers of a preserved eye.

In his time Filatov (1945) elaborated the operative techniques of partial lamellar keratoplasty by means of an FM-V trephine. Later the techniques of such transplantation, which did not differ essentially from those proposed by Filatov, were described by Paufique *et al.* (1948) and other authors. Various modifications of this operation have been described to date. We shall dwell on that used at the Filatov Institute.

1. Preparation of the operative field.

2. Removal of the opaque anterior corneal layers. Non-perforating trephination is carried out with the FM-V trephine in line with the position of the pupil (trephines 5 or 6 mm in diameter are used more often; the piston of the trephine is set at a distance of 0.3 mm from the cutting edge of the crown). The anterior layers of the cornea are then separated at a depth of the trephined incision with a round knife using pendulum-like movements.

3. Tailoring the graft. Non-perforating trephination of the cornea of the cadaver eye preserved by cold is perform-

ed with the same trephine. The graft comprising the anterior corneal layers is then removed with a round knife. Now Martinentz' method is used very widely, the cornea is first separated with a scraper in one part of the limbus, and then with a spatula, after which a graft of the needed diameter is excised with the trephine.

4. Positioning of the graft and its fixation. The graft is transferred to the defect in the cornea of the eye operated on, and carefully smoothed out with a spatula. A circle of an egg film prepared beforehand is placed over the graft and the surrounding cornea and the previously applied overlay sutures are straightened out and then tied.

A graft 6 mm in diameter is best secured with absorbable sutures passed edge-to-edge through the full thickness of the graft and through the anterior third of the corneal thickness. A binocular bandage is applied.

Partial lamellar transplantation of the cornea may be carried out without using the FM-V trephine. Non-penetrating trephination of the cornea can be performed with an FM-IV trephine, setting the piston at the needed distance from the edge of its crown. Trephine FM-III can also be used, making a very superficial cut in the cornea with it, then deepening the incision with a scraper along the line of trephination. In the absence of trephines, a non-penetrating incision of the cornea may be made with a scraper or Graefe's knife, having traced the required area of the cornea with it.

Bed-rest is prescribed for the first two postoperative days. The bandage is changed two days after the operation. Complications occurring in partial lamellar keratoplasty do not differ practically from those taking place after subtotal and total lamellar keratoplasty. These last are described below.

### SUBTOTAL AND TOTAL LAMELLAR CORNEAL TRANSPLANTATION

Subtotal and total lamellar transplantation of the cornea are the basic optic operations in richly vascularized leucomas covered with growth of cicatricial tissue.

In prescribing optic lamellar keratoplasty the ophthalmologist must be aware that the deep corneal layers of the eye to be operated on are transparent and the cicatricial changes are localized only in the anterior corneal layers.

This question, however, can far from always be settled with absolute assurance in all cases. Sometimes, in an intensive leucoma the deep layers of the cornea prove to be absolutely transparent, and, on the contrary, in a seemingly lesser intensity of corneal opacity, they may be considerably opaque. Examination in infrared light may be of value. If the structure of the iris is seen well in detail through the leucoma, this means that there is a large number of normal elements in the cornea; consequently, it may be presumed that the deep layers might be transparent. The presence of the anterior chamber is determined by means of ultrasonics.

In operation of subtotal and total lamellar keratoplasty, the opacified anterior layers are cut away from the entire, or almost entire corneal surface down to its transparent layers. The corneal wound surface is then covered with a graft consisting of the anterior corneal layers of a preserved cadaver eye. The operative techniques of total lamellar keratoplasty was first proposed by Filatov (1937, 1945) and later by Sourdille and Paufique (Paufique, Sourdille, Offret, 1948).

We shall dwell on the techniques of this operation, which we modified and currently use at the Filatov Institute. Since there is no difference in principle among all these methods, we shall only mention certain technical manipulations of other authors which might evoke interest of those engaged in keratoplasty.

Subtotal and total lamellar transplantation of the cornea differ only in the size of the graft. In total keratoplasty the whole anterior corneal surface is cut away and a graft 10 or 11 mm in diameter is transplanted depending on the diameter of the cornea of the eye operated on; in subtotal lamellar keratoplasty a graft with a diameter of 7 to 9 mm may be used while a small rim of the patient's cornea remains along the periphery.

There is no substantial difference in operative techniques between total and subtotal lamellar corneal transplantation.

The techniques of these operations are as follows.

1. Preparation of the operative field.

2. Excision of the opaque anterior corneal layers. A nonpenetrating trephination of the cornea is performed with a trephine of the needed diameter, specially intended for lamellar keratoplasty. If such is not available, trephines

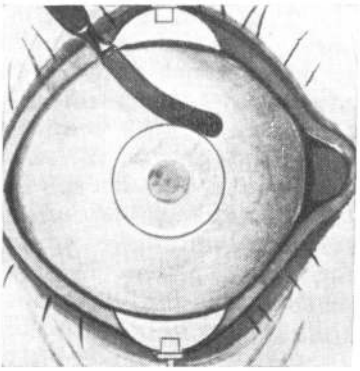


FIG. 75. A non-perforating incision of the leucoma made with a scraper along the circumference of the limbus.

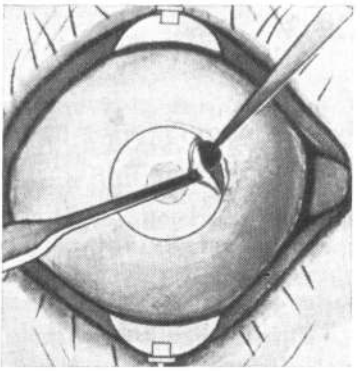


FIG. 76. Separation of the cornea with a round knife.

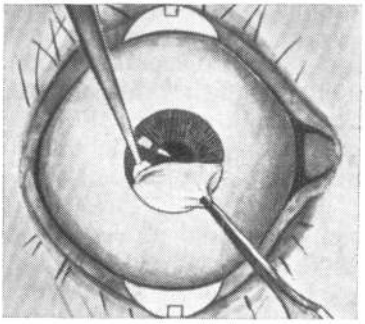


FIG. 77. Further separation of the opaque anterior layers of the cornea.

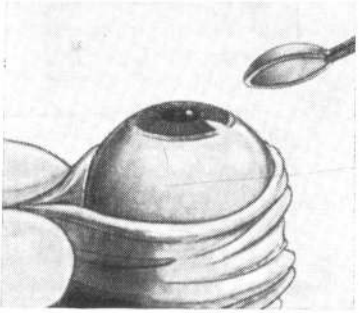


FIG. 78. A transplant comprised of anterior corneal layers grasped by forceps.

for subtotal penetrating keratoplasty can be used. In total lamellar transplantation the trephination is made in the area of the limbus with a trephine 10 or 11 mm in diameter; in subtotal lamellar trephination with trephines of 7, 8 or 9 mm at a distance of 1 or 2 mm from the limbus.

Trephination must be performed with extreme care, because the cornea can be easily perforated in any of its parts.

It is best to mark the line of incision superficially with the trephine and then carefully deepen it with a scraper. A non-penetrating incision of the cornea may be made in the area of the limbus with a scraper, with its blade set perpendicular to the plane of the limbus (Fig. 75).

After a non-penetrating round incision in the anterior corneal layers has been made the cornea is separated (Fig. 76).

The separated area of the cornea is tightly grasped with forceps and pulled forward, and separation of the cornea is continued by pendulum-like movements of a round knife (Fig. 77). It is most important to keep pulling the separated layer forward, because this makes it much easier to separate the cornea. Sourdille proposes anchoring the cornea with a sharp hook like a cataract harpoon, which is most convenient for removing thin corneal layers when it is difficult to hold the cornea with forceps. Paufique's forceps are very convenient for grasping thin corneal layers. If the transparent layers of the cornea are not exposed on removal of the first stratum, another one or several layers should be stripped in the same way.

3. Tailoring the graft. The graft which must comprise the anterior corneal layers is tailored from the donor's eye mostly in the same way as the recipient's opaque anterior corneal layers are removed. The only difference is that the tailored graft should not be held with forceps to avoid damaging it.

The graft is taken from cadaver eyes preserved at a temperature of 2 to 4°C. The corneas of eyes which have been in long preservation swell, as a rule. It is better therefore to use eyes, which have only been stored for two or three days, for lamellar transplantation.

A non-perforating cut is made in the cornea along the limbus with a trephine or a scraper. The cornea is then separated with a scraper to the needed depth along all its circumference. The graft is finally tailored with a round knife or scraper with which separation of the anterior corneal layers is continued. The graft is then applied to the cornea of the eye operated on (Fig. 78).

At present we widely use the Martinetz' method—separation of the cornea with a spatula. It is necessary to strive to tailor the thinnest possible graft because the thinner it is, the closer and more evenly it will fit over the surface

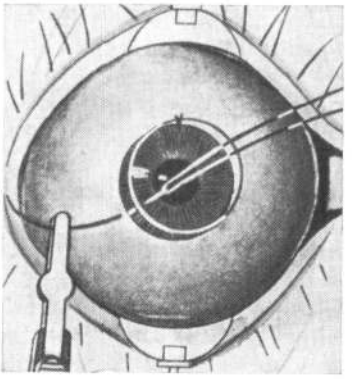


FIG. 79. Application of sutures through the graft and episclera at the limbus.

of the recipient's thinned cornea. It is difficult to make a thick graft fit the corneal surface well.

4. Fixation of the graft. Before fitting the graft over the corneal defect, bleeding from the severed vessels must be arrested. It is best to secure the graft with sutures, because all other methods do not always ensure its tight and even fit to the underlying cornea, which is essential for producing good results. The sutures are applied with corneal needles (Fig. 79).

It is convenient to use a catchless needleholder. The suture is passed through the full thickness of the graft and the limbal episcleral tissue or the tissue of the rim in the leucoma. Absorbable suture material or the finest silk is preferable. In subtotal and total lamellar keratoplasty it is necessary to apply at least six sutures: first at 12 and 6 o'clock, and then per two sutures from the lateral and medial sides. With a large diameter of the cornea or in cases when a very thin corneal layer is left on the eye operated on after the anterior layers have been removed, many sutures have to be applied to the graft to preserve the curvature of the cornea. They should be tied so that the graft would lie closely to and evenly on the underlying corneal tissue, because it heals rapidly and reliably only in close fit. The ends of the sutures are cut away. A 1 per cent

atropine solution and a 30 per cent sodium sulphacyl solution are instilled. Antibiotics are injected under the conjunctiva; a binocular bandage is applied.

The most severe complication in any type of lamellar keratoplasty is perforation of the cornea of the eye operated on when its opaque layers are being removed. When that happened at the beginning of the operation, it is best to discontinue it, return the separated cornea back in place and apply one or two sutures. In two or three weeks the patient may be operated on again.

If the perforation occurs when most of the anterior layers has been separated, then the site of the perforation must be carefully by-passed and removal of the corneal layers completed from the other side, to avoid making the opening larger. In careful removal of the anterior layers with smooth sawing movements without any jerks accidental injury of the cornea cannot be considerable and then such a complication will have no severe consequences.

When the iris adjoins the cut in the cornea, we can make it move away by performing a 2-mm incision in the sclera at a distance of 1 or 0.5 mm from and parallel to the limbus after suturing the graft; the air is then carefully let into the anterior chamber through the incision. The cut should be made on the side opposite to the opening in the cornea. The air is introduced through a special spatula, or using a needle with a blunt tip.

Still another complication is possible. With large exudate formed behind the cornea of the eye operated on, the presence of which is not always easily recognized when the cornea is opaque, during removal of the opaque anterior layers the cornea may be easily pierced and a layer of this exudate excised. If the cornea has been cut through for some length, a fistula may form, since the graft is devoid of endothelium.

The cutting of sutures when they are being applied may also be a complication occurring during the operation. Lamellar transplantation should always be carried out with optical microsurgical instruments (operating microscope or binocular magnifying glass).

After the operation of lamellar transplantation a binocular bandage is applied and bed-rest prescribed for two days. When there is no sharp pain in the eye operated on the bandage is changed two days after the operation and then

every day. If everything is alright, the bandage from the eye operated on may be removed in a few days.

There are usually no considerable signs of irritation of the eye operated on during the first two or two and a half weeks after the operation. Sharp irritation may suddenly develop in the third week during an uneventful course. Photophobia and lacrimation appear. Vessels grow vigorously into the graft and between it and the cornea of the eye. The transplanted cornea swells and opacifies. Vision often deteriorates to light perception.

Such outbreaks of inflammation are common in corneal transplantations on the eyes with leucomas resulting from a burn. This confirms data to the effect that in eye burns reactivity alters and consequently the inflammatory reaction develops as the organism's response to tissue transplantation.

Symptoms of irritation persist for two or three weeks after the onset of inflammation. Cicatricial tissue usually grows over the surface of the graft along all its circumference. This tissue may be coarse, fleshy or thinner. It rises like a threshold above the cornea along its periphery. The picture may be mistaken for an erosion, because there is a depression in the central part of the graft to which tissue growth has not yet spread. Staining the cornea with a 0.25 per cent fluorescein solution demonstrates the true character of this 'erosion' because it does not stain. It is a fact of considerable interest that phenomena of irritation remain until the tissue growth covers all the surface of the graft. As soon as that happens, manifestations of inflammation begin to subside, the vessels empty and the graft becomes more transparent. The organism seems to incapsulate the transplanted tissue, after which the inflammatory reaction to the transplantation subsides. In occasional cases the graft may resorb. Quite often the tissue growth is very thin and transparent. Further, when the graft is no longer swollen and the vessels are empty, its transparency may be restored to a great extent.

In lamellar keratoplasty performed for leucomas of other aetiology (dystrophy and degeneration of the cornea, scrofulosis, etc.) the postoperative period follows a much smoother course and in most cases a vigorous inflammatory reaction does not develop.

Corticosteroids are the most effective means for control-

ling the inflammatory reaction; cortisone or hydrocortisone is prescribed in instillations (five to six drops daily) and subconjunctival or, in occasional cases, intramuscular injections. Medication with corticosteroids should be begun seven or eight days after the operation. We usually inject cortisone through the skin at the lateral inferior orbital margin, using a 3 or 4-cm long needle, rather than under the conjunctiva. We use instillation and subconjunctival injections of cortisone on a wide scale in all types of corneal transplantation.

With the use of corticosteroids the postoperative period in lamellar corneal transplantation is much easier. In most patients prescription of cortisone has a rapid favourable effect. Quite often on the very next day signs of irritation begin to subside, the vessels empty and the eye causes much less trouble to the patient.

Proceeding from the data cited by Petrunya (1963) and some other authors it may be stated in all assurance that it is absolutely necessary to apply corticosteroids in keratoplasty.

We (Puchkovskaya, 1971) performed over a thousand operations for various types of lamellar corneal transplantation in leucomas of various aetiology, among which total and subtotal lamellar keratoplasty occupies the foremost place. Most of them were carried out for optic purposes in leucomas of burn aetiology.

We were convinced time and again, that transparency of the graft and the visual acuity of the eye, subjected to lamellar corneal transplantation, may greatly improve with time.

Petrunya (1963), on the strength of materials supplied by the Institute, showed that after total lamellar keratoplasty vision improved in the remote periods in 45 per cent of cases as compared with the vision immediately after the operation. The overall percentage of the increase in visual acuity after subtotal and total lamellar keratoplasty was 87.7 per cent. The least favourable results were obtained after ammonium burns.

In view of the severity of the damage to the corneal tissue caused by the burn, visual acuity after the operation is usually equal to several hundredths, and in only about 13 per cent of the patients who had been operated on for leucomas of burn aetiology vision was 0.1 and higher.

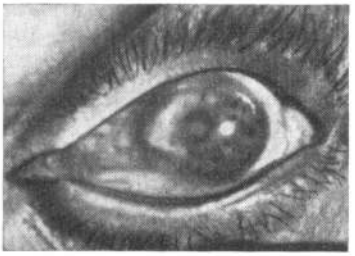


FIG. 80. Patient P. A total vascularized leucoma of the left eye after a burn. Visual acuity 0.02.

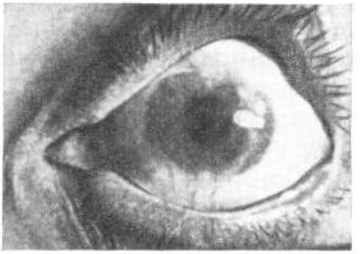


FIG. 81. Patient P. The same eye after total lamellar keratoplasty. Term of observation — five years. Acuity of vision 0.4.

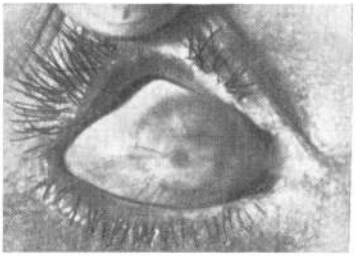


FIG. 82. Patient P-v. A total vascularized leucoma of the right eye after a burn with molten metal. Acuity of vision —counting fingers at the face.

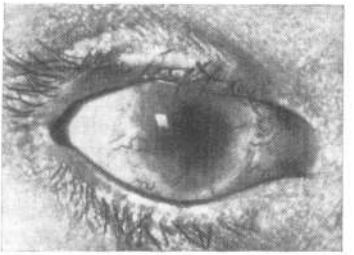


FIG. 83. Patient P-v. The same eye after total lamellar keratoplasty. Acuity of vision 0.5.

Lamellar keratoplasty, however, is an operation of choice in cases with such leucomas, because perforating corneal transplantation holds no promise for such patients.

Sometimes optic results may be achieved only after the second or third operation for total lamellar corneal transplantation, when the first operation had proved ineffective. The following case histories illustrate the results of lamellar keratoplasty in leucomas of burn aetiology.

P., a 36-year-old female. Burn of both eyes with a silicate oxygen alloy. Total vascularized leucomas of both eyes. Visual acuity—right eye 0.03, left eye 0.02 (Fig. 80).

After total lamellar keratoplasty the visual acuity of the left eye improved to 0.4. The follow-up period of five years (Fig. 81).

P-v, a 26-year-old male. Total vascularized leucoma of the right eye after a burn with molten pig-iron. Visual acuity—counting fingers at the face (Fig. 82). After total lamellar keratoplasty, visual acuity 0.5. Follow-up period of one year (Fig. 83).

It should be borne in mind that after total keratoplasty the refraction of the eye alters. In patients in whom the transplanted cornea is transparent, hypermetropia of 4 to 7 dioptries is often found. This should be taken into account in deciding on the type of keratoplasty when the other eye is healthy.

Summing up the above stated, it may be concluded that total and subtotal lamellar transplantation of the cornea is the basic operation in total leucomas of burn aetiology, and also in vascularized leucomas and superficial corneal opacities of other origin, if the deep corneal layers of the eye to be operated on have retained transparency. Such keratoplasty, as the safest, is also indicated in operations on an only eye, on aphakic eyes and in infants.

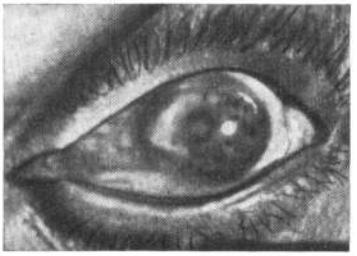
## PERIPHERAL LAMELLAR CORNEAL TRANSPLANTATION

We proposed and developed the method of peripheral lamellar transplantation of the cornea (Puchkovskaya, 1955, 1960). Observations have proved its high effectiveness as an optic operation. We distinguish it because the main principle of this operation is absolutely different from other types of corneal transplantations.

The attainment of the optic effect is based on stimulating the regenerative properties of the corneal tissues of the eye operated on, and not on replacing the opaque leucoma with tissues of a transplanted transparent cornea, as is the case in all other types of perforating and optic lamellar corneal transplantation.

In 1947 we began employing the operation of peripheral lamellar keratoplasty on patients with post-burn leucomas who had at least the smallest area of healthy transparent cornea on the damaged eye.

In cases with incomplete vascularized leucomas and an area of undamaged corneal tissue at least 2.0 to 2.5 mm wide, the anterior corneal layers were removed from all the surface except this area. In doing so, we strove to reach the transparent layers in the pupillary region. A graft



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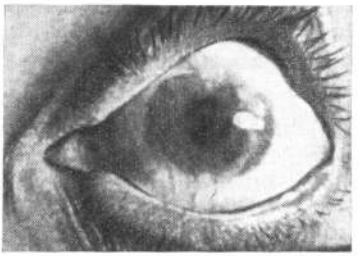

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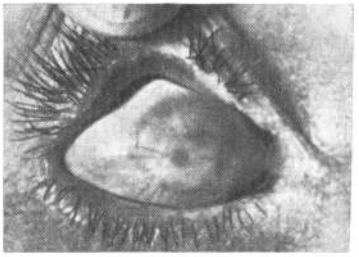

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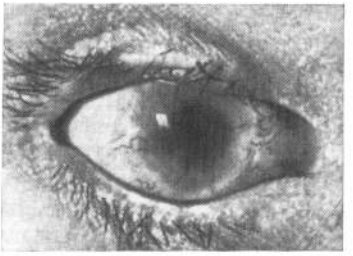

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shaped like a horseshore was tailored from the anterior corneal layers of an eye preserved in the cold. It was then applied along the periphery of the cornea at the limbus in that part of it, from which the anterior layers had been removed. The area of the healthy undamaged cornea was left uncovered. The graft was fastened to the limbus with several sutures. The uncovered central part of the cornea constituted the wound surface. We presumed that in the first days after an operation performed by this method, epithelization of the wound surface would occur, and after that regenerative processes would develop under the epithelium the way it happens in removal of limited superficial leucomas or in healing of non-supurative ulcers and defects in the cornea. These assumptions proved correct. By staining the cornea with an 0.25 per cent fluorescein solution we established that on the second postoperative day the central part of the cornea not covered with the graft was almost entirely covered with epithelium. Epithelization occurred due to proliferation of epithelium from the normal healthy corneal tissue, and not due to the epithelium of the graft. Subsequently regenerative processes develop under the epithelium leading to thickening of the excised part of the cornea. If, on removing the opaque corneal layers, the transparent layers in the centre can be reached, the optic results of the operation would be very good.

In optic perforating and lamellar keratoplasty all our endeavours are aimed at preserving the transparency of the graft because it is the optic zone of the cornea. In peripheral lamellar keratoplasty we are not concerned with the transparency of the graft, since its purpose lies in obstructing the growth of cicatricial tissue from the surrounding area over the cornea. If the wound surface of the cornea is left uncovered by the graft along its periphery, then cicatricial tissue will grow over the cornea from the direction of the limbus, often forming a denser layer than there had been before the excision. We witnessed favourable results from the leucoma excision proposed by Castroviejo, but only in removal of fine, limited superficial corneal opacities, around which there was healthy corneal tissue.

Opacification of the horseshoe graft has no effect on the central optic zone of the cornea not covered with it, in other words, it exerts no influence on the optic result of the operation. Besides being a 'barrier' the graft fulfills

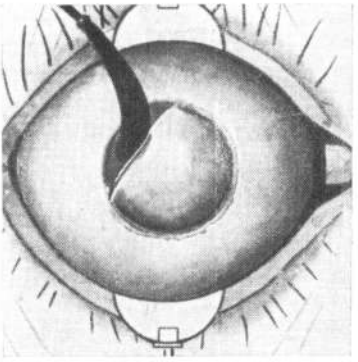

FIG. 84. Exfoliation of the cornea with a scraper on the border of the transparent corneal area and the leucoma.

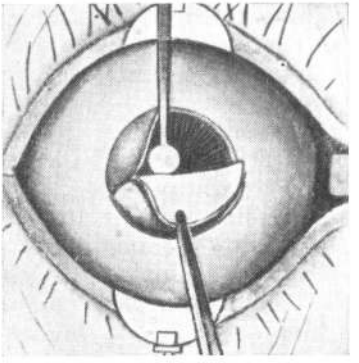

FIG. 85. Cutting away the opaque anterior layers of the cornea with a round knife.

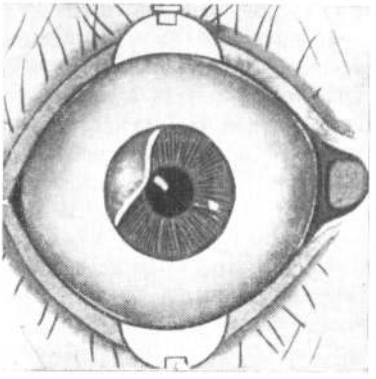

FIG. 86. The area of the healthy cornea remains untouched.

a therapeutic function too, because it is a preserved tissue containing biogenic stimulators.

The transparency of the central optic corneal zone depends on how far it was possible to reach the transparent areas in the centre in removing the opaque corneal layers, and on the course of the postoperative period.

Thus, the fundamental principle of this operation is to use the regenerative properties of the cornea of the eye operated on and not to replace the leucoma with a corneal graft.

The operative techniques of our peripheral lamellar keratoplasty are as follows.

1. Preparation of the operative field.

2. Excision of the anterior corneal layer. A non-perforating incision is made in the cornea along the limbus in line with the position of the leucoma with a scraper, the blade of which is held perpendicular to the corneal surface. A cut is also made on the border of the limbus and the area of the healthy undamaged cornea (the cut here is made within the limits of the transparent corneal tissue). The cornea is separated with a scraper where it was cut along the border between the leucoma and its healthy area (Fig. 84), its edge is grasped with forceps and the layers of its opacified parts are cut out with a round knife (Fig. 85). The area of the healthy cornea remains untouched (Fig. 86).

3. Tailoring the graft. In peripheral lamellar corneal transplantation the graft should be shaped like a horseshoe or semi-circle, because it is transplanted onto the corneal wound surface at the limbus. That is why it is first necessary to estimate the approximate graft circumference. After the preserved eye has been washed with an aqueous solution of brilliant green and instilled with a 30 per cent sodium sulphacyl solution, a non-perforating cut is made in the cornea with a scraper in the region of the limbus for a length corresponding to the size of the graft. Using the same scraper, the cornea is separated along the limbus to a width of 1.0 to 1.5 mm on the line of the previously made incision. Since the inner border of the graft should be very thin, it is best to complete its fashioning with Graefe's knife, which is advanced through the separated peripheral part of the cornea and brought out through its anterior layers at a distance of 1.5 to 2.0 mm from the limbus toward the centre of the cornea. Then the graft is finally cut off along its entire length with sawing movements of the knife (Fig. 87), as a result of which its inner border will be slightly uneven. The tailored graft should have the shape of a horseshoe, a thin inner border and a width not exceeding 1.5 or 2.0 mm.

4. Fixation of the graft. The graft is applied over the wound surface of the cornea of the eye operated on, from

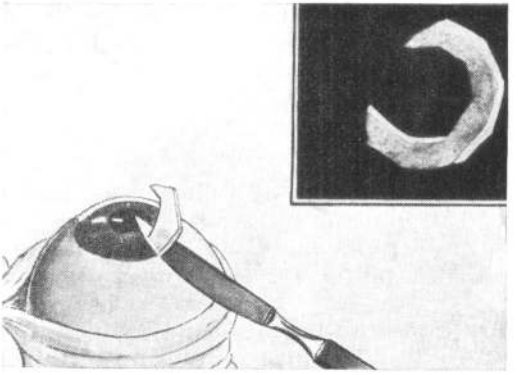

FIG. 87. Tailoring a 'horseshoe' graft.

which the anterior layers have been sliced away so that the outer border of the graft will correspond to the line of the limbus while both its ends fit to the borders of the healthy corneal portion. Absorbable corneal sutures are then applied. Their number usually does not exceed six or seven and depends on the size of the graft. The sutures are passed through the full thickness of the outer border of the graft and the episcleral tissue of the limbus (Fig. 88). If the graft is too long, the surplus is cut away with Graefe's knife.

Thus, the central part of the cornea remains uncovered by the graft.

The main possible complication is perforation of the cornea during removal of its anterior opaque layers, in which case the operation cannot be completed as peripheral lamellar transplantation: it is then necessary to tailor a graft corresponding in shape to that of the wounded corneal surface and cover the wound completely with it, so that the opening in the cornea would not be at the very border of the graft, otherwise a fistula can form.

The postoperative period in peripheral lamellar corneal transplantation is characterized by a milder course. Only a few patients suffered from inflammation on the third week after the operation. These patients should be treated in the same way as those with an inflammatory process developing after total lamellar transplantation.

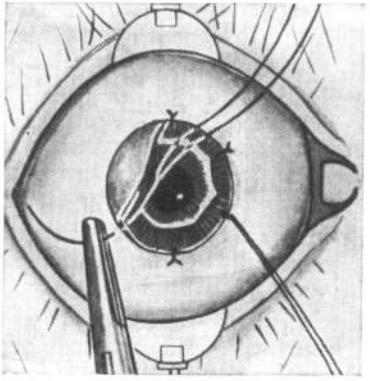

FIG. 88. Application of sutures to the graft.

After the operation the surface of the eye operated on is at first uneven, because the thickness of the cornea varies in different places. The area of the healthy cornea is of a normal thickness; in the central part, not covered with the graft, there is a depression, since the anterior corneal layers there have been cut away, at times to a considerable depth, and, finally, the thickness of the corneal periphery depends on the thickness of the graft, but at any rate, it is more than the thickness of the central part. In the long run this disparity in the thickness of the cornea disappears completely.

The patient may be discharged in five to six weeks after the operation, on the average. It should be pointed out that in peripheral lamellar corneal transplantation the regenerative processes in the eye operated on persist over a lengthy period of time. They concern mainly the transparency and thickness of the cornea. A considerable improvement in the transparency and shape of the cornea was noted in all patients who returned for a check-up examination.

When the eye operated on is examined in remote periods after the operation, it is practically impossible to discern the boundary between the normal area of the cornea and the corneal surface from which the anterior layers had been removed, just as it is impossible to define the graft boundaries. There is no room for doubt that true regeneration of corneal tissue develops with the tissues of the piece of

a normal cornea contributing to the process. The epithelium of this area first covers the wound surface from which the anterior layers were excised, and then regenerative processes gradually develop under the epithelium resulting in the restoration of the normal thickness of the cornea. The transparency of the restored corneal tissue is evidence of the genuine nature of regeneration.

The optic results of peripheral lamellar keratoplasty depend on the initial condition of the eye subject to operation. In many patients visual acuity after the operation improved to 0.5-0.6 and even more.

Thus, peripheral lamellar keratoplasty may yield optic results which are considered to be very successful even in the more efficacious type of keratoplasty—partial perforating corneal transplantation. Moreover, the former has great advantages (to say nothing of the fact, that in leucomas developing after a burn, perforating transplantation fails to produce any optic results at all), since it is carried out without opening the eyeball, and therefore the danger of secondary glaucoma and some other severe complications encountered in perforating keratoplasty is excluded. Another major advantage consists in the fact that in peripheral lamellar keratoplasty we have no fear of possible opacification of the graft afterward, since the optic zone is the cornea of the eye itself operated on, while opacification of the peripheral horseshoe graft has no substantial influence on the vision. In most patients peripheral lamellar transplantation of the cornea produced a good optic result, and in some the result was very good.

The following case illustrates the effectiveness of the operation.

**M., a 21-year-old male. Extensive vascular leucoma of the right eye after a burn with a flame. Visual acuity 0.05 (Fig. 89). The other eye is normal.**

**After peripheral lamellar keratoplasty visual acuity 0.4 (Fig. 90). Follow-up period of nine years.**

Peripheral lamellar transplantation produces very good results also in leucomas of other aetiology, both in adults and in children. The postoperative period is attended with much less marked inflammatory reaction than in total lamellar transplantation.

According to Kuksa (1966), visual acuity after peripheral lamellar transplantation increases in 86 per cent of the

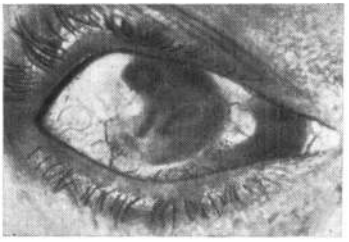

FIG. 89. Patient M. An extensive vascular leucoma of the right eye after being burnt with a flame. Acuity of vision 0.05.

FIG. 90. Patient M. The same eye after peripheral lamellar keratoplasty. Acuity of vision 0.4.

patients, in 50 per cent of cases it improves from 0.1 to 1.0.

It is necessary to take into account two basic indices when patients are selected for peripheral lamellar corneal transplantation: (1) the presence of an area of a healthy corneal tissue at the expense of which regeneration of both the epithelium and the stroma will eventually take place; (2) the transparency of the deep corneal layers in the area corresponding to the pupil.

We can now state with full assurance that peripheral lamellar transplantation should be preferred to all other types of optic perforating and lamellar keratoplasty in all cases in which it is indicated, particularly when operating on an only eye or on aphakic eyes in leucomas of burn aetiology.

## CORNEAL ALLOPLASTY

Alloplasty of the cornea (keratoprosthetics) also belongs to the group of optic operations which can be performed in leucomas. Attemps to use transparent materials for making a 'window' in a leucoma have been undertaken since long ago.

Filatov tried again and again to implant transparent plates of various materials into the corneal layers. Vodovozov studied corneal alloplasty in experiments, but these attempts all ended in failure. Beginning with 1962 reports have appeared in the literature on the successful

use of keratoprostheses (corneal alloplasty) in the clinic and in experiments (Cardona, 1962, 1965; Cardona *et al.*, 1962; Stone *et al.*, 1965; Krasnov and Orlova, 1967; Krasnov, 1970; Ushakov, 1968; Bedilo, 1969, 1970; Fedorov, 1970; Puchkovskaya *et al.*, 1970; Zhivotovsky, 1970, and others).

Some authors used non-perforating alloplasty, others—perforating. Certain authors performed alloplasty when, in our view, the condition of the cornea called for transplantation, but not for alloplasty. It is, of course, essential to adhere very strictly to the indications for alloplasty, the main one of which is the failure of keratoplasty. Keratoplasty is undoubtedly more physiological than alloplasty and should be performed in the first place; only when it has failed should alloplasty of the cornea be undertaken.

Implants (keratoprostheses) of various shapes and different materials are used.

We shall discuss only one type of operative techniques and implantation of one type of keratoprostheses, which consist of a plastic optic rod 2.5 to 3.0 mm in diameter and a tantalum perforated disk for fixation 6 to 7 mm in diameter.

The techniques of corneal alloplasty consist in the following.

1. Preparation of the operative field. Akinesia. Retrobulbar, epibulbar and infiltration anaesthesia. Bridle suture applied to the superior and inferior straight muscles.

2. Incision of the conjunctiva along the limbus and its separation by 10 to 12 mm (Fig. 91).

3. Non-perforating incision of the cornea along two thirds of the circumference of the limbus (Fig. 92). Separation of the cornea at a depth of its posterior third (Fig. 93).

4. Application of three or four absorbable sutures to the edge of the cornea and episclera at the limbus (Fig. 94). The sutures are tied once with a double surgical knot.

5. Perforating trephination of the cornea with an FM-III trephine 2.5 to 3.0 mm in diameter, i.e. a diameter corresponding to that of the optic rod of the keratoprosthesis (Fig. 95).

6. Should the lens be opaque, it is extracted. The length of the back part of the optic rod differs, depending on whether there is a lens in the eye operated on. For each patient there should be two keratoprostheses with the cor-

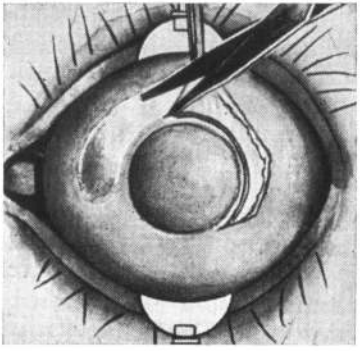

FIG. 91. Incision of the conjunctiva along the limbus and its separation.

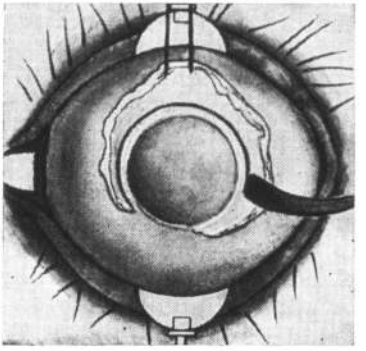

FIG. 92. A non-perforating incision of the cornea along the limbus.

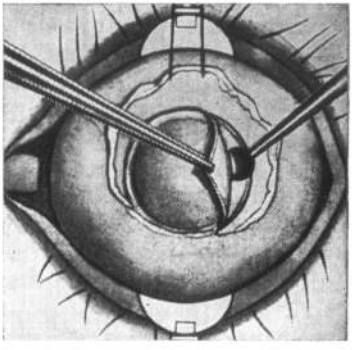

FIG. 93. Separation of the cornea.

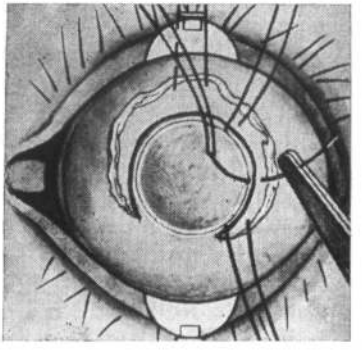

FIG. 94. Application of sutures to the edges of the cornea and sclera.

responding curvature of the fixation plate, and short and long back part of the optic rod. It is always possible to have a previous knowledge on the presence and thickness of the lens due to ultrasonic diagnosis, but it is not possible to know whether the lens is transparent or opaque. For that reason it is best to have two ready implants with measurements corresponding to those of the cornea of the eye to be operated on.

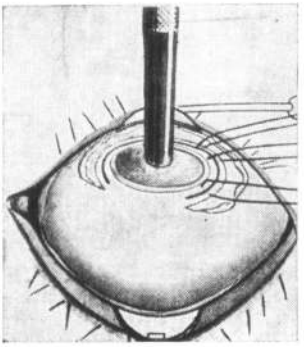

FIG. 95. Perforating trephination of the cornea.

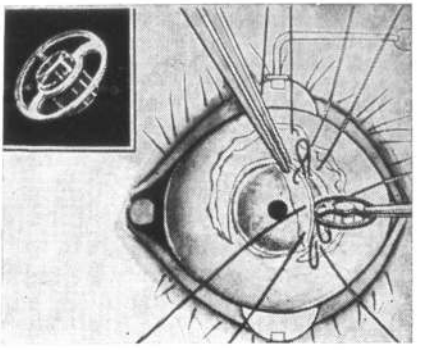

FIG. 96. Introduction of the keratoprosthesis into the trephined opening.

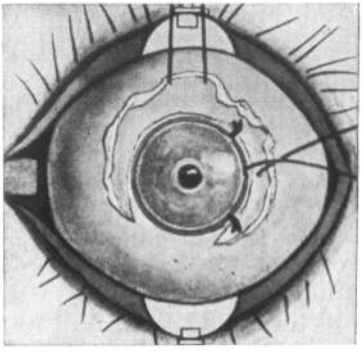

FIG. 97. Tying the sutures.

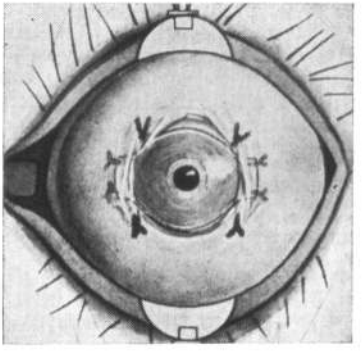

FIG. 98. Sutures have been applied to the conjunctiva.

7. The sutures are drawn apart and the keratoprosthesis is inserted between the anterior and posterior layers of the cornea (Fig. 96). The back part of the optic rod is inserted in the trephined opening in the posterior corneal plate, while its front part into the opening in the anterior plate.

8. The sutures are tied (Fig. 97). Two or three additional sutures are applied. If the anterior corneal layers are thin, a graft of anterior corneal layers taken from a preserved eye is transplanted to secure the implant.

9. A lamellar graft with scleral flaps and an opening in the centre is tailored.

10. The epithelium is scraped away from the anterior surface of the cornea. The graft is then applied to the surface and sutured to the episclera from the medial and lateral sides of the limbus with absorbable sutures. Additional sutures are applied.

11. Silk sutures are placed on the conjunctiva so that the scleral flaps of the graft would be entirely covered with the mucous membrane (Fig. 98). A binocular bandage is applied and bed-rest prescribed for ten days as in perforating keratoplasty.

Here are the results of corneal alloplasty.

Patient Kh., a male. Total vascularized leucoma of the cornea of both eyes after a burn with an aniline dye. Visual acuity of the right and left eye—correct light projection (Fig. 99).

Preliminary lamellar keratoplasty produced no results.

After perforating alloplasty (Fig. 100) visual acuity improved to 0.7. A year later the keratoprosthesis began baring and to keep it in place was covered with a graft of lip mucosa. Eight months later the mucosa in the region of the optic part of the keratoprosthesis was cut and a film was revealed behind the optic rod (Fig. 101). Visual acuity 0.05. The film and opacified lens were removed (Fig. 102). Visual acuity 0.4.

Growth of a film behind the optic rod and rejection of the graft are often encountered in the postoperative period. Corneal ulceration sometimes develops around the optic rod which then progresses and terminates in loss of the keratoprosthesis. In such cases it is necessary to cover the anterior corneal surface anew with a graft of the oral mucosa or the conjunctiva of the neighbouring areas. This too, however, does not always protect the implant from falling out.

Other authors working for many years in the same direction observed the same phenomena. It is no mere chance that ever new types of techniques of corneal alloplasty are being proposed.

Thus, Castroviejo (1968) and Cardona (1970) have recently proposed not to separate the patient's cornea in perforating alloplasty, but to secure the keratoprosthesis inserted into the perforating opening in the cornea with a special 'nut' at its posterior surface (in the anterior chamber) and with a disk located in front of the cornea at its ante-

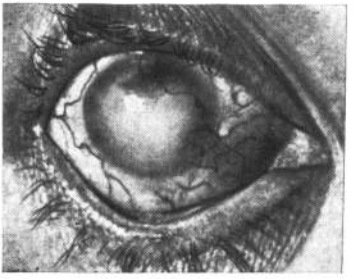

FIG. 99. Patient Kh. A total vascularized leucoma of the right eye. Acuity of vision—correct light projection.

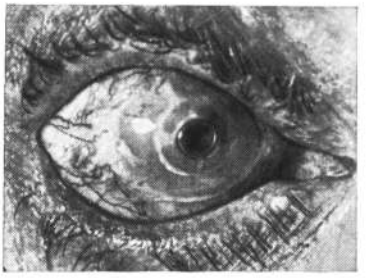

FIG. 100. Patient Kh. One year after perforating alloplasty of the cornea had been performed.

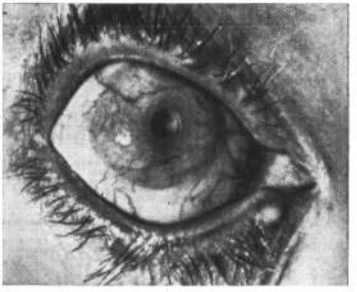

FIG. 101. Patient Kh. A film is visible behind the optic part of the keratoprosthesis.

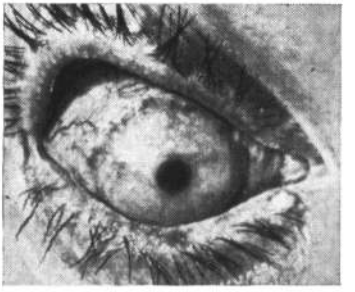

FIG. 102. Patient Kh. After removal of the film and the opacified lens.

rior surface. They contend that the disk covering the cornea protects it from ulceration.

It is difficult to imagine that such coarse manipulations (because the lens, even if it is transparent, is removed during the operation without fail) will be well tolerated by the eye. The future will reveal what prospects this technique will have, and, very possibly, it will find application under certain conditions.

Considering the fact that in some patients keratoplasty produces no optic results, corneal alloplasty is undoubtedly a valuable and very necessary method.

According to the authors mentioned above, the optic effect after alloplasty may be lasting. It should be borne in mind, however, that not all authors and not in all cases followed strict indications for alloplasty.

We have become convinced on the basis of illustrations to reports and publications, and demonstrations of films at congresses on corneal alloplasty, that these operations were not infrequently performed in cases in which keratoplasty was indicated. For that reason the effectiveness of alloplasty has actually been studied insufficiently as applied to eyes with a complicated condition at the onset and with leucomas in which corneal transplantation is not indicated. Research into this problem claims top priority, because in precisely such patients alloplasty provides the only chance for restoring vision.

* * *

The results of research and observations at the Filatov Institute of Eye Diseases and Tissue Therapy and analysis of current literature discussed in this monograph testify to the fact that burns, which are among the most serious types of traumas, are characterized by features inherent only in this type of injury.

Much has been attained in recent years in the study of the pathogenesis of the eye burn process and elaboration of new effective methods for treating eye burns and their sequelae. The introduction of these methods into practice provided more active measures for maintaining and restoring visual functions in severe burn damage. There are still many problems awaiting solution, however, which are of primary importance for correct understanding of the burn process at its different stages, and, therefore, for successful treatment of patients with severe eye burns.

The most typical feature in the course of severe eye burns is the progressing deterioration of the condition of the eyes and involvement of its deep parts (the choroid, retina and crystalline lens) in the pathological process, and of areas of the conjunctiva and cornea, which had not suffered the burn directly.

It is extremely important to ascertain precisely the degree of the burn as early as possible, because this determines the physician's tactics in the first hours after the burn. Such methods do not exist to date, and the clinical signs

at the early stages do not always reflect the severity of the burn.

It is necessary to continue developing more reliable and early methods for defining the depth of the damage caused by the burn to the eye tissues. Certain progress has been made in this field. The use of infrared rays gives some idea of the extent of transparency of the deep corneal layers. Examination of the cornea in polarized light pursues the same aim.

Study of the ultrastructure of the damaged tissues by means of an electron microscope and comparison of the findings with the clinical manifestations of the burn may possibly promote an advance in this field.

Knowledge of the intricate laws governing the burn process in combination with the clinical manifestations of the burn will provide more assurance for determining the indications for early surgical intervention in severe burns and for judging, with more grounds, the need for urgent plastic surgery of the conjunctiva or cornea.

The elaboration of precise methods, accessible for use, for determining the degree of damage to the eye tissues is one of the basic tasks.

Histomorphological study using methods of supravital tissue staining demonstrated that, in the first period of the burn, only the anterior corneal layers, which had come into direct contact with the burning agent, suffered necrotic changes, while the deep lying areas proved to be less damaged. A considerable part of tissue elements is in a state of paranecrosis, i.e. under favourable conditions they can still revive to vital activity. The data also testify that the zone of corneal damage increases progressively in the first days after the burn, and this condition of the tissues is typical of all types of burns irrespective of their aetiology.

Study of the organism's immune reactions to the burn showed that progression of the burn process in the eye may be caused by accumulation of toxic products in the zone of tissue damage which, in turn, leads to auto-intoxication and autosensitization.

Autotoxic reactions together with immediate deep disturbances in the vital activity of the cell arising as a result of its contact with a damaging agent may serve as a trigger mechanism of the further advance of the pathological process in eye burns. That is why the test of a purposeful

therapeutic effect on this aspect of the pathogenesis proved valuable for developing the most rational therapy of severe eye burns.

Urgent keratoplasty (necrectomy with simultaneous lamellar corneal transplantation) elaborated at the Filatov Institute requires further clinical testing on a large number of cases, which will help to work out strict indications for its use. This problem is closely linked with the elaboration of methods for determining the degree of the burn.

Clinical and experimental studies have shown that immunotherapy of eye burns employed in the form of subconjunctival injections of burn convalescent serum and included in a complex of therapeutic measures in eye burns causes a decrease of the toxic effect of the burn on the manifestation of the inflammatory reaction in the eye, and reduces the number of complications during the burn process and intensifies the regenerative properties of the eye during healing.

We became convinced in the high therapeutic effectiveness of burn convalescent serum and plasma, having applied it in combined treatment of eye burns in more than 400 patients; 63 of these patients had moderate burns (50 eyes) and severe burns (20 eyes), and were given immunotherapy as an independent measure, in other words, besides the serum and plasma of convalescents, they received only disinfectants and mydriatics.

Bearing in mind that disturbances of immunogenesis are an important, but not the only link in the pathogenesis of eye burns, it is necessary to continue the search for new therapeutic agents stimulating vital processes in the eye tissues and directed, first and foremost, at normalizing regeneration.

The further improvement of the techniques of early surgical intervention in an eye injury is necessary, because these operations should be least damaging.

The study and development of more effective means of early plastic surgery of the eyelids employing methods for fixation of skin grafts with biological and synthetic glue will provide an opportunity to avoid the development of cicatrices on the skin, and, therefore, additional severe destructive changes in the tissues of the burnt cornea.

The study and development of methods for active early

surgical intervention may be of utmost importance in the treatment of ocular burns.

Control of tissue incompatibility, which develops on the background of a general distorted reactivity of the organism, acquires particular significance for more successful outcomes of keratoplasty in cases with postburn leucomas.

New methods and new agents for suppressing the reaction of biological incompatibility can undoubtedly promote the attainment of better biological and optic results after transplantation of the cornea.

It is necessary to study further the possibility of using plastic materials for implantation into the cornea. It is precisely corneal alloplasty that may prove valuable for patients with sequelae of severe and particularly severe eye burns as a result of which coarse cicatricial leucomas with almost total loss of corneal elements develop, and in which keratoplasty has no effect. New operative techniques, new types of keratoprostheses and accumulation of clinical observations are necessary to obtain optic results in patients with such most aggravated leucomas.

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# Author Index


Alberth, B. 115, 119, 139, 158, 186
Alexandrov, V. Ya. 15, 194
Allen, J. 186
Allgöwer, M. 33, 186
Anderson, R. E. 30, 186
Arruga, H. 139, 186
Averbakh, M. I. 86, 114, 186

Barg, Ts. M. 90, 186
Barkhash, S. A. 157, 186
Bedilo, V. Ya. 177, 186
Belavia, M. 89, 186
Berezinskaya, D. I. 18ff, 53, 85f, 112, 186
Blinova, L. I. 22, 89, 187
Bochkareva, A. A. 92, 187
Bogdashev, B. S. 92, 187
Breebaart, A. 187
Brown, S. I. 30, 77, 94, 187
Buchmann, H. 112, 187
Bursuk, G. G. 89, 187
Bushmich, D. G. 120, 157, 187

Callahan, A. 139, 147, 187
Campbell, F. W. 14, 28, 187
Cardona, H. 177, 180, 187
Carpenter, C. P. 18, 187
Castroviejo, R. 158, 170, 180, 187
Chambers, L. A. 16, 189
Cherikchi, L. E. 187
Chernova, A. A. 8, 19, 28, 33, 52, 92, 95, 112, 187f
Chistik, I. Ya. 95
Christensen, L. 16, 188
Cresnel, H. 92, 192
Cruthirds, A. 90, 188
Csapody, J. 139, 147, 188

Damato, F. J. 91, 188
Dao Suang Cha, 112, 188
Dashevsky, A. I. 113, 188
Davydova, I. B. 91, 188
Day, T. 28, 188
Delong, G. 95, 188
Dembo, M. A. 89, 188
Denig, R. 26, 92, 113f, 188
Dolenek, A. K. 95, 115, 188
Dugelny, G. A. 8, 201
Duke-Elder, W. S. 13, 16, 23, 62, 77, 86, 91, 112, 188
Dzhaliashvili, O. A. 35, 52, 188

Engel, F. 188
Ershkovich, A. I. 95, 188

Fedorov, N. A. 189
Fedorov, N. A. 34, 39, 50f, 177, 189
Filatov, V. P. 16, 113, 115, 158f, 161, 176, 189
Fischer, F. P. 91, 189
Flosdorff, E. W. 16, 189
Feher, J. 93, 200
Fradkin, M. Ya. 90
Franceschetti, A. 121, 189
Frank, W. 112, 187
Friendenwald, J. S. 18f, 21, 189

Galchin, S. A. 113, 196
Gässler, H. 53, 90, 189
Getman, V. P. 148, 189
Gnädinger, M. C. 94, 189
Godina, N. D. 92, 189
Goldenberg, A. Z. 87, 189
Goldfeld, N. G. 115, 189
Golovchenko, V. G. 27, 200
Goryainov, V. S. 87, 189
Gostev, V. S. 35, 189
Graefe, 85
Grant, W. M. 13, 17, 72, 112, 189f
Grosz de, J. 190
Gudkova, L. S. 158, 190
Guilleri, O. 85, 190
Gundorova, R. A. 85, 190
Gurevich, S. K. 89, 190
Gushcha, G. P. 133f, 190

Hamburger, F. A. 190
Harley, R. D. 18, 90, 190
Haselmann, G. 90, 190
Heinc, A. 15, 21, 113, 115, 190

Heydenreich, A. 74ff, 190
Hollwich, F. 112, 190
Honegger, H. 85, 190
Hughes, W. F. 21, 53, 85, 190

Ilchenko, A. V. 89, 92, 112f, 159, 190
Isaeva, G. V. 12, 27, 32, 74, 89, 92, 113, 190

Jansa, J. 85, 192
Jedrosz, I. 90, 199
Johnstone, M. A. 85, 191

Kalinichenko, N. I. 89, 195
Kanbai, G. G. 87, 191
Kaplunovich, P. S. 22, 26ff, 29, 33, 74ff, 77, 89, 95f, 112, 191
Karady, S. 191
Karmysheva, V. Ya. 68, 191
Kartamyshev, A. I. 35, 191
Kazakova, V. N. 97, 191
Kazal, L. A. 191
Kaznelson, A. B. 8, 12, 27ff, 33, 53, 60, 89, 113, 191
Khayutin, S. M. 16, 191
Khvoshch, R. A. 96
Kishkina, V. A. 112, 191
Klima, M. 21, 26, 90, 191
Klyutsevaya, E. I. 76, 152, 191
Kolen, A. A. 139, 147, 192
Kolker, I. I. 34, 192
Kolstad, A. 16, 192
Kononova, A. A. 26, 192
Kopit, R. Z. 21f, 32
Koptsiovskaya, R. S. 152, 192
Korsakov, G. F. 32, 201
Koryakina, I. K. 97, 192
Kozina, 90, 91, 198
Kosyakov, P. N. 192
Kovalev, D. S. 74, 192
Kozdoba, A. Z. 33, 192
Krasnikov, P. G. 52, 192
Krasnov, M. M. 177, 192
Krejci, L. 85, 192
Krivenkov, A. G. 35, 52
Kruger, R. 89, 192
Kuhn, A. S. 90, 192
Kuksa, V. D. 158, 175, 192
Kulakhmetyeva, M. G. 92, 192
Kuprianowicz, W. 92, 192
Kurlov, I. N. 139, 147, 193
Kuvatov, G. G. 193
Kuzina, E. I. 87, 193

Ladyzhinskaya, P. A. 92
Langer, Ts. M. 95, 193
Langschmidt, K. 90, 193
Lapshina, A. V. 109, 193
Lazarenko, V. I. 74, 92, 96, 119, 193
Leahey, B. D. 95f, 193
Lebekhov, P. I. 14, 68, 89, 193
Legeza, G. V. 133, 137, 139, 147, 149, 193
Leigh, A. G. 193
Levtyukh, V. I. 120, 193

Magalnik, E. V. 87, 193
Magilnitsky, S. G. 95, 193
Makhlin, I. M. 194
Malova, L. M. 52, 192
Marmorshtein, F. F. 113, 188
Maruyama, T. 23, 194
Masunova, N. N. 87, 194
Matyashina, O. M. 194
McLaughlin, R. S. 86, 112, 194
Merte, H. 34, 35, 194
Miller, B. 26, 36, 194
Milovidova, A. N. 53, 92, 113, 194
Milstein, A. Ya. 32
Molnar, L. 92, 194
Morozova, O. D. 114, 194
Muchnik, S. R. 15, 22, 116, 197

Nagy, F. 90, 194
Nasonov, D. N. 15, 194
Nazarova, E. F. 66, 194
Nemec, J. 89, 194
Nemetz, U. P. 91, 194
Nepomyashchaya, V. M. 26, 66, 86, 88, 93, 97, 119, 194f
Nguyen Chong Nyan, 157, 195
Nikulina, N. B. 89, 195
Novokhatsky, A. S. 66
Novotny, L. 85, 195

Oansea, I. 112, 195
Ochapovskaya, N. V. 26f, 34, 53f, 62, 75, 79, 195
Offret, 161, 195
Oppel, V. V. 32, 195
Opsahl, R. 16, 192
Orlova, E. M. 177, 192
Orlowski, W. J. 112, 195

Parkhomenko, M. E. 74, 112, 195
Parkhomenko, M. K. 195
Parkhomovsky, M. V. 89, 95, 195
Passow, A. 16, 112, 195
Pastukhova, A. N. 92, 187
Paterson, Ch. A. 75, 195
Paton, T. 158, 195
Paufique, L. 158f, 161, 195
Pavlyuchenko, P. I. 8, 26, 53ff, 72, 77, 89, 92f, 95f, 113, 195f
Petrunya, P. I. 158, 167, 196
Pfister, R. R. 22f, 30, 75, 196
Pichler, 112
Pikhtar, V. I. 86
Pillat, A. 91, 196
Pirie, A. 16, 33, 196
Pogoretsky, A. P. 150, 196
Pokrovskaya, A. I. 92, 196
Poltinnikov, I. H. 27, 60, 74, 196
Polyak, B. L. 24, 45, 53, 55, 69, 72, 77, 86f, 91, 93, 112f, 196
Porshnev, A. I. 158, 196

Prantsuz, G. A. 92, 196
Pravosud, H. G. 139, 196
Preobrazhensky, P. V. 91, 93, 119, 196
Protopopov, B. V. 32, 90, 113, 196
Puchkovskaya, N. A. 8, 13ff, 18, 21, 24, 26, 28, 66, 97, 110, 116, 119, 121, 123, 139, 147, 149, 158, 167, 169, 177, 197f
Pur, S. 90f, 198

Regamey, R. 198
Rejchrt, B. 92, 200
Rodigina, A. M. 12, 92, 113, 198
Rougier, J. 158, 198
Rozenkrants, K. B. 52
Rycroft, B. W. 158, 198

Safarli, Sh. R. 87, 198
Sallai, S. 23, 198
Saman, K. 90, 91, 198
Sapezhko, 130
Saushkina, N. K. 8, 12, 27f, 53, 89
Savinskaya, G. A. 93, 198
Schenk, 91
Schütz, F. 33f, 50, 198
Schulz, V. A. 89, 187
Segal, P. 96, 198
Semenov, A. D. 109, 198
Sewitt, S. 33, 198
Shaier, E. G. 9
Shershevskaya, O. I. 27, 86, 89, 198
Shulgina, N. S. 33ff, 51, 198f
Siegrist, J. 33, 186
Sigal, M. Z. 199
Skrzypczak, K. 90, 199
Skurkovich, S. V. 34, 39, 50f, 199
Smidovich, S. P. 199
Smith, H. F. 18, 187
Sourdille, G. P. 161, 163, 195
Stein, M. R. 75, 199
Sterger, K. 34, 199
Stone, W. 177, 199
Svoboda, J. 89, 199

Tagibekov, K. K. 148, 150, 199
Tartakovskaya, A. I. 8, 11f, 27, 29, 60, 199
Teterwak, J. 199
Thies, O. 53, 69, 77, 113, 199
Tikhova, V. A. 89, 200
Trusov, M. S. 92, 200

Uglova, T. G. 90, 93, 112, 200
Uhde, G. L. 85, 200
Ushakov, N. A. 8, 32, 69, 85, 177, 200

Valova, M. 92, 200
Valul, L. S. 93, 200
Vasinca, M. 112, 195
Vejdovsky, V. 113, 115, 200
Verzin, A. A. 200
Vilenkina, A. Ya. 90, 200
Vinogorov, D. R. 21f, 32, 200
Vints, I. M. 200
Vodovozov, A. M. 176
Voino-Yasenetsky, V. V. 21, 34, 75f, 200f
Votockova, J. 74f, 201

Wagenaar, J. W. 113, 201
Wagenmann, A. 86, 201
Wan-Heining, 16
Wekka, L. 112, 195
Weller, C. A. 30, 187

Yaudegide, O. V. 92
Yushko, N. A. 121, 201

Zagora, E. 13, 60, 62, 86, 201
Zaikova, M. V. 134, 147, 201
Zats, L. B. 8, 32, 201
Zelenina, E. E. 92
Zenkina, L. V. 113, 201
Zhinkin, L. N. 32, 201
Zhivotovsky, D. S. 177, 201
Zilberg, L. A. 35, 201
Zolotareva, M. M. 115, 201
Zwahlen, P. 90, 201

# Subject Index


acetylcholine, 90, 92, 94, 100
acid anions, 17, 19
acid burn(s), 17ff, 25, 79, 81
  experimental, immunotherapy in, 39ff
  first aid, 85
  metabolic processes, 20
  pathomorphological changes, 18f
  primary lesion, 19f
acid(s), direct effect on corneal tissue, 18, 26
adrenaline, 95
alkali, direct burning action, 20ff
alkaline albuminate, 22
alkaline burn(s), 20ff, 80f
  direct effect, 20f
  experimental immunotherapy in, 39ff
  first aid, 85
  histomorphological studies, 21f
anion-protein complexes, 19
ankyloblepharon(s), 130, 137
antiburn antitoxic serum, 39, 44, 51
atropine, 94
auto-antigens, 34, 37f
auto-intoxication, 30ff, 38f, 48, 97ff, 115
autologous blood, 92f
autosensitization, 33ff, 38f, 97ff, 115

BAL, 85
blood substitutes, 109
burn convalescent serum, 39, 43ff, 51f, 94, 97ff, 184
  antitoxic properties, 51
  desensitizing effect, 51
  toxicity, 51
burn disease, 32f
burn process, 24, 51, 61
  auto-intoxication, 30ff
  autosensitization, 33ff
  clinical peculiarities, 62ff
  corneal metabolism, 26f
  injury to vessels, 26f, 71f
  and nerve plexus of cornea, 27
  stages, 29f, 60f
  typical manifestations, 24f

canthi correction, 137
cataract, 81
  cryo-extraction, 154
chemical burn(s), 12
acid, *see* acid burn(s)
  aetiological factors, 13
  alkaline, *see* alkaline burn(s)
  experimental, immunotherapy in, 39ff
  first aid, 85f
  lime, 47, 50
ciliary body, 59, 73, 92, 94
collagenase, 30
conjunctiva, burns of, 58, 64f, 67, 69ff, 76f, 92
conjunctival cavity, 87
  cicatricial deficiency in anophthalmos, correction of, 147ff
  microflora, 87f
cornea, 12ff
  burn(s), *see also* corneal tissue, burnt, 59, 64f, 67, 72ff, 76ff
  frostbite, 16
  perforation, 120ff, 126, 165
  opacification, 79f
corneal alloplasty, 176ff, 185
  optic effect, 182
  postoperative period, 180
  techniques, 177ff, 180
corneal paracentesis, 112f
corneal tissue, burnt, 12ff
  changes, stages of, 29f
  glycogen content, 28
  inflammatory changes, 68
  metabolic disturbances, 13, 17, 19, 23f, 26
  mucopolysaccharides, 29
  oxygen absorption, 28
  proteins, antigenic properties, 34f, 37
  reactive changes, 68
  sensitivity, 12f, 17
  swelling, 28
  toxic products, 32f, 37
  vitamin content, 28, 33
corneal transplants, 122
  lamellar, 123ff
corticosteroids, 95, 166f
crystalline lens, 59, 152ff

Denig's operation, 92, 115
Descemet's membrane, 15
DETA, 85

echogram(s), 152f
ectropion, 128, 130ff
EDTA, 85, 94
  clinical observations, 119ff
  experimental research, 116f
entropion, 130, 142f
eye burn(s)
  acid, *see* acid burn(s)
  aetiology, 12ff
  alkaline, *see* alkaline burn(s)
  antibacterial therapy, 86ff
  chemical, *see* chemical burn(s)
  classification, 53ff, 57
  complications, 81f
  drug treatment, 84ff
  early concomitant symptoms, 59, 73f
  experimental, immunotherapy in, 39ff
  first aid, 85f
  general disturbances, 82f
  immunotherapy, 97ff
  mild, *see* mild burn(s)
  moderate, *see* moderate burn(s)
  particularly severe, *see* particularly severe burn(s)
  remote complications, 110
  severe, *see* severe burn(s)
  severity, 62f, 119
  surgical treatment, 112ff
  thermal, *see* thermal burn(s)
  tissue therapy, 110
eye-burn disease, 13, 24f, 32, 38
eyelashes, transplantation, 137
eyelids, 64f
  burns of, 58, 64f, 69f, 78
  cicatricial deficiency correction, 143ff
  free margin restoration, 136f
  plastic surgery, 128f

FiBS, 110

immunotherapy, 97ff, 184
experimental, 39ff
inflammatory process, 24, 27f, 38, 43ff
intra-ocular pressure, 59, 68, 73ff, 81, 94f, 154
iridectomy, 151, 156
iridocyclitis, 59, 66, 73f, 81, 94
iridotasis, 152
iris, 59, 65f, 73, 94, 120f

keratoplasty, 157ff
  urgent, *see* urgent keratoplasty
  lamellar, 157f
  lamellar-perforating, 121
  optic, 139
  optic lamellar, *see* optic lamellar keratoplasty
  perforating, 157f, 169f
  peripheral lamellar, *see* peripheral lamellar keratoplasty
  tectonic, early, 115, 120ff
  therapeutic, early, 123ff
  urgent, *see* urgent keratoplasty
keratoprostheses, 177, 179f

lagophthalmos, 129
leucoma(s) of burn aetiology, 68, 80f, 152ff, 157, 161
  optic operations for, 157ff, 169ff
limbus, 58, 78

Martinetz' method, 160, 163
mild burn(s), 58f, 88
  clinical picture, 63ff
  treatment, 109
  visual acuity, 64
moderate burn(s), 58f, 110
  acuity of vision, 66
  clinical picture, 65ff, 72
  complications, 67
  treatment with burn convalescent serum, 98, 105, 109f
mydriatics, 94, 98

Ochapovskaya's classification, 54
optic lamellar keratoplasty, 158, 170
  complications, 165f, 173
  inflammation in, 166f, 173
  optic results, 167ff
  operative techniques, 161ff
  partial, 159f
  subtotal and total, 160ff
oxygen therapy, 89f

palpebral fissure, gaping, 128f
paranecrosis, 15, 17, 22
particularly severe burn(s), 58f, 110
  clinical picture, 77ff
  complications, 81f
  intra-ocular pressure, 74
  treatment with burn convalescent serum, 98, 105, 110
  visual acuity, 80
passive anaphylaxis test, 35f
Passow's operation, 112
pathogenetic therapy, 38
Pavlyuchenko's classification, 54
peripheral lamellar keratoplasty, 169ff
  optic results, 175f
  postoperative period, 173ff
  principle, 172
  techniques, 172f
Polyak's classification, 55ff
Prausnitz-Kuestner skin-allergic test, 35
prosthesis, thin-walled, 149
protein denaturation, 13, 15f, 19, 23, 25, 34f, 37

reactive hypertension, 74f

Sapezhko's operation, 130
sclera, burns of, 58, 77f
scopolamine, 95
severe burn(s), 58f, 110
  clinical picture, 69ff
  complications, 73f
  intra-ocular pressure, 73f
  treatment with burn convalescent serum, 98, 105, 110
  visual acuity, 73
SH-groups, 25
sphincterectomy, 151
symblepharon(s), 92, 127f, 130, 137
  extensive or total. 108
  partial, 109
  surgical treatment, 138ff

thermal burn(s), 12, 14ff, 25f, 79, 81
  aetiology, 13
  biochemical shifts, 16
  clinical picture, 64
  denaturation of proteins, 16f
  experimental, immunotherapy in, 39
  by hot metals, 14, 63
  metabolic disturbances, 1.
  morphological disturbances, 14ff
  by steam and hot water, 14, 65
Thies' classification, 53
thio-TEPA, 96
torfot, 110

urgent keratoplasty, II5ff

vasoconstrictive drugs, 91
vasodilators, 90ff, 95, 97, 100

*TO THE READER*

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A broad aspect of the eye burn disease is provided in this monograph on the basis of experimental research and many years of clinical experience at the Burn Department of the Filatov Institute of Eye Diseases and Tissue Therapy in Odessa. The clinical characteristics of various types of eye burns and the common features and peculiarities of the course followed by a process in burns of various aetiology and different degree of damage are discussed.

The fundamental principles of pathogenetic therapy of eye burns based on the morphological, biochemical and immune disturbances caused by the burn are examined. New methods for treating eye burns and their sequelae proposed and developed by the authors are described. The main attention is focussed on the treatment of severe and particularly severe eye burns which often lead to irreparable consequences—cicatricial complicated leucomas, adhesions between the eyelid and eyeball, secondary glaucoma and loss of the eye.

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Prof. N. A. Puchkovskaya shows particular concern for the training of young specialists; the ophthalmological school she founded is perpetuating the traditions established by Academician V. P. Filatov.
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